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Semiotic Thresholds, Between Arts and Biological Science: Green Technology and the Concept of Phytomining

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Abstract: *This paper documents the creative process of the Between Arts and Biological Science: Green Technology and the Concept of Phytomining project. The project represents an iterative series of concepts, models, and installations about the Anthropocene which culminates in design ideas for the creation of a functional environmental remediation system. The paper is given in three parts: historical conception, small scale modelling and the creation of a working phytoremediation system. Phytoremediation systems use plants to extract, sequester, and/or detoxify pollutants; common examples include heavy metals and human waste. Such solutions tend to be mechanically simple but biologically complex. The rationale behind the creation of this system was to create an autonomous remediation process that could function without external input, such as one that would be needed if economic or environmental resources are scarce, as is common in times of political, economic or environmental crises. This project is an exploration of how biological and technological systems can be integrated using plants and algae as a test medium - primarily Taraxacum officinale and Chetomorpha algae. The work uses several theoretical post-hoc constructions to explore the nature of design in remediation systems, these being: the Anthropocene, and phytosemiotics. This paper works at the art-engineering interface as it illustrates the process of going from conceptual models to full-scale construction of a working system. The paper does not seek to draw definitive conclusions but promote debate. We believe our primary contribution in this area is to give working examples of how biotic and abiotic sign systems can be integrated and designed to create products that are beneficial to humankind. Humankind in the age of the Anthropocene*[1].

Keywords: Phytomining; Phytoremediation; Phytosemiotics; Molecular Semiotics; Biosemiotics; Anthropocene

1.0 Introduction

"I never made a painting as a work of art, it's all research" - Pablo Picasso

The research included in this paper is predicated on an exhibition and a round table discussion of the project Between Arts and Biological Science: Green Technology and the Concept of

Phytomining which was presented at the 2nd international conference of Numanities, Kaunas University of Technology, Kaunas, Lithuania, May 2015.

In this paper, we lay out our rationale for using artistic works to explore the development of biosemiotic theory, particularly in relation to the semiotic thresholds that divide biotic and abiotic systems. The paper then introduces literature on phytoremediation, phytomining processes and the biosemiotic discipline that explores sign processes in plants, known as phytosemiotics. We go on to explore two scale models of phytoremediation schemes, one in an aquatic environment (Chetomorpha algae) and one land based (Taraxacum officinale). Which is followed by an exploration of a full-scale living phytoremediation system that the authors have constructed. We end the paper with a discussion about the different perspectives on the thresholds to semiosis, and the neglected role that human influences have played in this debate.

The installations given in this paper form part of a larger series of work in relation to net art, open-code strategies, audio-visual artistic practices, and biohacking that have been exhibited in numerous locations throughout Europe and with other artists[2]. This scheme of work has been informed by discourses in the arts and engineering about the Anthropocene[3]. The exhibitions were not an experiment and do not seek to draw conclusions, and were not created for the purposes of education but instead to provoke debate, and produce possible new ideas around semiotic thresholds in biological systems. Hence, the installations are not to be taken as representations from which to draw generalizable conclusions, but as objects that help to explore the idea of the Anthropocene. Regrettably, we did not have the economic resources to create exhibits of transgenic plants, but this was not an impediment to discussing the issue, with conference attendees, or within this paper.

1.1 Semiotic Thresholds and the Artistic Method

Basic questions concerning the function of biological systems have been posed by authors such as Emmeche (2002: 166) and Kull, Emmeche, and Favareau (2011: 76) who specifically questioned “How can anything (e.g. molecule x) that initially does not have a function, obtain a function?” This proposition concerning molecular function in semiotics has also been previously articulated by Kawade (1996: 201):

> How can communication and signification, the main subject matter of semiotics [...], take place in the world of molecules, especially in the most elementary forms of molecular interactions?

Almost 20 years later, this question remains pertinent, and whilst Kawade (1996) was concerned with protosemiotic molecular interactions at a more granular level than the subject matter given in this paper, our investigations are driven by the same stimulus to apply semiotics to biochemical systems. In addition, we hope that this paper will contribute to the on-going debate around the location of lower semiotic thresholds in biological systems (Kull, 2009; Nöth 2001). As of this writing, there is no current consensus upon exactly where the semiotic threshold of biological and cultural systems lie, but instead a variety of competing ideas (Rodríguez Higuera and Kull 2017).

Consequently, this is an area of current importance in biosemiotics and has been so since Umberto Eco (1976: 19 - 28) initiated a conversation about *natural boundaries*, and how one might distinguish between the semiotic and non-semiotic in biological processes. It is the difficulty of separating the semiotic from the non-semiotic (Nöth 2001a, c), that makes exploration of the topic worthy. Naturally the topic of semiotic thresholds in biological systems has been concerned with the lower boundaries of protosemiosis, and processes that barely fulfil “the minimum requirements of semiosis and is hence just above the semiotic threshold between the semiotic and the non-semiotic world, if such a threshold exists at all.” (Nöth 2001b:13). Various positions have been taken by biosemiotic researchers as to where the genesis point of semiosis is located in biological systems. Rodríguez Higuera and Kull (2017) suggest that these can be broken down into five broad positions:

1. **Umberto Eco**: “The phenomena on the lower threshold should rather be isolated as indicating the point where semiotic phenomena arise from something non-semiotic, as a sort of 'missing link' between the universe of signals and the universe of signs” (Eco 1976: 21)
2. **Kalevi Kull**: “When trying to formulate once again our understanding of the precise conditions for semiosis to appear, i.e. the lower semiotic threshold, we listed a series of specific characteristics of the mechanism that brings semiosis into existence. These characteristics may include memory, self-replication, recognition, agency, inside-outside distinction, codes, semiotic controls, etc.” (Kull 2009: 9)
3. **Søren Brier**: “Sign making is the threshold between cybernetics and semiotics. To create a difference that makes a difference is to establish a sign for it (an Interpretant) in an embodied mind. Before this, it is only second-order cybernetic signals – or quasi-semiotic, according to Peirce. The whole subject area of cybernetic information theory is therefore quasi-semiotic. Beneath this is the physicochemical level, which is generally best described in terms of energy, matter, and causality by natural forces (Secondness) but in the long term does have Thirdness processes that develop ‘natural law’ through symmetry breaking and habit formation in evolution.” (Brier 2008: 391)
4. **Winfried Nöth**: “Peirce draws this dividing line between dyadic and triadic interactions. His semiotic threshold is the one which leads from dyads of interactions between physical causes and effects to triadic interactions in which an organism interprets (forms an interpretant of) its environment, the signifying stimulus (representamen),relative to a goal (the object) which is distinct from the environmental stimulus” (Nöth 1994: 3)
5. **Luis Emilio Bruni**: “It is customary to recognize the cell as the most elementary integration unit for semiosis, i.e., as the lowest semiotic threshold.” (Bruni 2015: 1086)

Other scholars' works such as Jesper Hoffmeyer (Hoffmeyer 2009, 1998, 1996), Thomas Sebeok (Sebeok 2001), Alexei Sharov (Sharov 2015, Sharov and Vehkavaara 2014), Jordan Zlatev (Zlatev 2009) and many more are also key in relation to these works, but the categories employed are used to illustrate the breadth of positions taken in relation to where a semiotic thresholds may be. One can see from the different position taken that “there is no strong consensus on the way to define semiotic threshold as it pertains to biosemiotics” (Rodríguez Higuera and Kull 2017: 16). Equally, once more we would echo the sentiment in Rodríguez Higuera and Kull (2017: 2) “that there is no consensus on the location of these possible thresholds should be taken as an advantage in discussing issues on the possibility of sign action”. Given then that there is neither consensus on the way to define semiotic threshold, nor on where such a threshold might lay, it is the author’s contention that an exploration of the subject is justified.

The artistic installations given in this paper are designed to promote questions about what and where the biosemiotic thresholds might be. The method employed is not to reach definitive conclusions, as to do so would be farfetched, as has been shown above by the different conceptualisations of thresholds. In addition, the function of art in this paper should not be seen as a pedagogic tool to teach or instruct, but rather its function is disruptive and designed to encourage philosophical introspection, discussion and debate (Dissanayake 2009). Kull (1998:15) has highlighted that culture and nature are not in binary opposition and that the point at which we cross a biosemiotic threshold is dependent on how define our particular use of theory, Rodríguez Higuera and Kull (2017: 123) went on further to say that:

> The question whether everything is properly semiotic after we have crossed the lower threshold will still depend on how we conceptualise the specifics of our semiotic theories, but the idea of the thresholds generally helps semioticians parcellate areas of specific research with their specific methods and backgrounds

Therefore, the artistic approach employed in this work offers semioticians an opportunity to critique how they have conceptualised the specifics of biosemiotic theories.

1.2 The Anthropocene

Discourse about the Anthropocene focusses on the significant human impact on the Earth and atmosphere emphasizing the central role of humankind in geology and ecology. For example, the planet's ecosystem is not able to biodegrade the excess production of human-manufactured materials such as aluminium, concrete, and plastics (Jordan 2011). Geological deposits from non-biodegradable substances produce a signature that is different from the earlier Holocene epoch and the decay-resistant human produced waste will inevitably leave identifiable fossil and geochemical records (Waters et al. 2016). In addition to the environmental consequences to the biosphere from increased carbon and methane emissions, these are becoming increasingly important issues (Buis and Ramsayer 2015).We explore these concepts in relation to the idea that the insecure nature of politics, economics and climate change could force humans to come up with more sustainable and innovative solutions to design problems that are both autonomous but also not limited to the traditional divisions between biology and technology. Hence, the paper is divided into three parts:

1. Historical conception of remediating metals and the philosophy of biological systems
2. Two scale models of phytoremediation and phyto-mediated systems, and
3. A full-scale example of how phytoremediation might work in real life.

The outcome of the scheme of work is the construction of an autonomous phytoremediation system, which is currently being implemented in Berlin (see Figures 5 & 6). The phytoremediation process functions by utilising the capacity of microorganisms, fungi, plants, or their enzymes to transform the natural environment into a state with less contaminants. Such a state however cannot be said to be new, but is simply altered by the phytoremediation process into a more acceptable condition. As such, the use of the term autonomous is not to be taken as synonym for a closed system, as such, systems in biological terms are never truly closed but are a composite of the interactions of microorganisms, fungi, plants, and enzymes. An additional cleavage between traditional divisions of biology and technology that we are interested in is transgenic plants[4]. This is because just as through phytoremediation, plants can be used by humans to remediate an environment, transgenic plants specifically can be genetically engineered to remove heavy metals and other pollutants from soils. Whether the plants are planted in new locations or genetically modified, they both represent examples of how humans conceive of their actions in the Anthropocene period, which this paper seeks to explore. However due to financial restraints, the project did not have the resources to culture transgenic plants species to use in our models. We draw from both of these processes to explore discourses or sustainable life solutions. Initially however before such concepts are developed, a background to phytoremediation and phytomining processes will be given as they form the scientific basis of this work.

1.3 Phytoremediation and Phytomining

Phytoremediation as defined by Meagher (2000: 153) is "the use of plants to extract, sequester, and/or detoxify pollutants." The term's etymological root being from the Greek word for a plant or vegetation – φυτό. A subcategory of phytoremediation is the concept is phytomining. Phytomining simply put is an environmentally-friendly alternative to conventional mining, it is aimed at extracting metals from the soil via plants such as hyperaccumulators (see section 1.4). Such plants are sown, harvested and burnt, and then the metal is extracted from smelted bio ore. If some metal still remains in the soil, the same process can be iteratively repeated until the desired result is obtained (Brooks et al. 1998). It is important to also consider that pollutants are not all land based but can leach into aquatic systems (Cheng et al. 2002, Terry and Bañuelos 2000), and the seas and oceans require remediation themselves (Warr et al. 2013) this will be addressed further in the installation of scale model 1.

This process is applied to contaminated land or aquatic environments, as well as human waste. This process can be used to remediate both common metals such a lead and copper, as well as rare elements like gold (Msuya, Brooks, and Anderson 2000). It is seen as a less invasive mode of mining than other practices such as strip-mining, or mountain top removal. Typically phytoremediation extracts heavy metal contaminants such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Lead (Pb), and Zinc (Zn). These metals are often found in faecal (biliary) excretion; hence the cleaning of human waste is one of the primary application of phytoremediation. An illustrative example of the different phyto-technological applications are given in Table 1.

Table 1. Different plant species and their applications, adapted from ITRC (2001: 29)

Mechanism	**Media**	**Typical Contaminants**	**Plant Types**
Phytostabilisation	Soils, sediments, sludge	As, Cd, Cr, Cu, Pb, Zn	Herbaceous species, grasses, trees, wetland species
Rhizodegradation	Soils, sediments, sludge, ground water	Organic compounds, pesticides, solvents containing Chlorine	Herbaceous species, grasses, trees, wetland species
Phytoaccumulation	Soils, sediments, sludge	Ag, Au, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn	Herbaceous species, grasses, trees, wetland species
Phytodegradation	Soils, sediments, sludge, ground water, surface water	Organic compounds, Chlorinated solvents, some inorganics, phenols, pesticides, munitions	Algae, Herbaceous species, grasses, trees, wetland species
Phytvolatilisation	Soils, sediments, sludge, ground water	Chlorinated solvents, some inorganics	Herbaceous species, grasses, trees, wetland species
Evapotranspiration	Groundwater, surface and storm water	Water soluble organics & inorganics	Herbaceous species, grasses, trees, wetland species

Phytoremediation is less centred on the collection of metals, but more on the remediation of the immediate environment. This approach was chosen because of its mechanical simplicity, and its diverse applications to a wide variety of environmental situations (Cunningham and Ow 1996). There are a plethora of other Phyto prefixed environmental remediation processes such as:

Phytodegradation, Phytostimulation or rhizodegradation, Phytovolatilisation, Phytoextraction, Rhizofiltration, and Phytostabilisation (UNEP. 2012). The rhizo- prefix here refers to the rhizomes, which are the plant's root nodules. It is also important to state in regard to these two concepts that ecologically, phytoremediation is more complex than just plants, and plants themselves exist as complexes of organisms, including internal and external fungi, and bacteria, and it is this interspecies semiosis of these different organisms that produces the desired effect of phytoremediation. The scale models of phytoremediation systems given in this paper, as such are only ever partially 'phyto-centric' representations of a more complex biological system as it would exist in nature. Consequently, we recognise that the fungi, and algae that are the subjects of this paper are not taxonomically linked to the plant kingdom, as such the phyto-prefix is something of a malapropism; given that the chemical signalling and other biological processes of these species do not work in the same way as plants.

1.4 Hyperaccumulators

Plants that are used in phytoremediation have some very specific biochemical properties, specifically a process named hyperaccumulation. Hyperaccumulators, are plants that accumulate up to 100 times the average concentration of heavy metals in their roots (Baker 1981). There are approximately 400 plant species that are known to be hyperaccumulators, their phylogenetic properties are thought to have been developed to protect the species from herbivores and pathogens (Cappa and Pilon-Smits 2013). Hyperaccumulators are generally chosen for phytoremediation. There are several pathways by which the metals or other pollutants are remediated, but perhaps the two commonest routes are vacuolar compartmentalization and chelation (Roychoudhury et al. 2012, Chaney et al. 1997). Essentially the contaminant is either trapped inside the root cell (vacuolar compartmentalization) to prevent it circulating around the plant. Or the contaminant is modified into a safer form (chelation) and circulated in the plant, typically exiting the plant to the atmosphere through the leaves, a process that is called Phytovolatilization (Brooks 1998) – See Figure 7.

The means by which heavy metals are rendered into a safer less toxic form through a plant's metabolic pathways has been of interests to biochemists for a long time. It should perhaps then come as no surprise that bacterial genes have been bioengineered to facilitate these processes. For example the phytoremediation of Mercury in contaminated soil can be accomplished by bioengineering transgenic plants (like tobacco - Nicotiana) that contain bacterial genes which are expressed at a particular point in the photosynthesis cycle. These genes – MerA (Fox and Walsh 1982) and MerB (Begley, Walts, and Walsh 1986) - catalyse the mercury into a safer, less reactive state so that it can undergo Phytovolatilization and be released back into the atmosphere (Heaton et al. 1998).

2.0 Conceptual Basis of Phytomining

The investigation of phytomining employed an array of theoretical position from both artistic and engineering based epistemological paradigms to conceptualise the ideas in relation to environmental remediation. This includes investigations into the integration of silicon-based electronic components with carbon-based organic components, exploring the semiotics models of plants, and the principles of environmental design.

2.1 Phytosemiotics

Phytosemiotics is the semiotic study of plant life, although perhaps one of the less considered topics in semiotics, it still falls firmly within the aegis of biosemiotics. To be more specific the *Routledge Companion to Semiotics* describes phytosemiotics as "the study of communicative behaviours in plants" (Cobley 2009: 166). Krampen (1994: 728) went further than this to break phytosemiotics down into three further categories: plant to plant communication, plant to human communication, and plant to animal communication. Other related areas of semiotics include Mycosemiosis (Kræpelin 2003) – the semiosic study of fungi. Deely (2014) concisely links the evolution of biosemiotics to the reconciliation of Saussurean and Peircean semiotics (Kiryushchenko 2012, Petrilli 1990, Watt 1978). One may also link Deely, Williams, and Kruse (1986) to this development. As Deely (2014: 282) has highlighted the existing work on Phytosemiotics is largely confined to Martin Krampen (1981), John Deely (1982, 1990), Kalevi Kull (Kull 2000), and Kane Faucher (Faucher 2014). Phytosemiotics is also touched upon at varying points in Cobley et al. (2011). However, by and large the semiosics of plant life is a less studied area than other more contemporary areas of semiotics. Nevertheless, Phytosemiotics as a lens for the philosophy of plant signalling systems helped to form the basis of the prototypes of phytoremediation which are given in the following section, as well as being used a form of post-hoc analysis for design structures. We have chosen to use the term phytosemiotics through this paper because of the etymological and morphological concordance with phyto-remediation. But the authors acknowledge that it would be more correct to refer to vegetative semiosis when dealing with process at a more cellular or molecular level (Kull, 2009).

3.0 Arts as a Method

The method we are employing in this paper is known as arts-based research, this can be defined as:

> The systematic use of the artistic process, the actual making or artistic expressions in all of the different forms of the arts, as a primary way of understanding and examining experience by both researchers and the people that they involve in their studies. (McNiff 2008: 29)

This paper uses art installations a way to debate and re-think semiotics concepts. This is a method that may not be familiar to all researchers especially those from more traditionally scientific fields. For whom the question then arises, why use arts as a source of data or method of enquiry?

This approach was pioneered by Ruddolf Arnheim – See Arnheim (1954, 1966) and Sussane Langer – See Langer (1951), Langer (1953), and also has been used in medical contexts, such as McNiff's *Arts as Medicine: Creating a Therapy of Imagination* (McNiff 1992). However, we feel that one of the best authors to explain the rational for this approach is Theodor W. Adorno who suggested that art can be meaningful in presenting alternative ways of being in the world (Adorno 1984). The fluidity in artworks allows us to re-conceptualize ideas in ways that can be useful to examining their character, or more simply as a process of furthering a person's understanding of constructs that have ill-defined boundaries:

> The work of art is not a totality in the sense of a structure integrating the parts: once objectified, the work keeps on producing itself in response to the tendencies at work in it (Adorno 1984:255)

We are engaging in a dialectical confrontation between the static and the dynamic processes of fixed biological realities and the socio-cultural use and interpretations of them. For this reason, art makes a useful thinking tool to highlight the tensions between such processes. Adorno explains this in relation to the fact that art is autonomous from society whilst simultaneously being part of it (Adorno 1974), additionally he stated:

> All aesthetic questions terminate in those of the truth content of artworks [...] the truth content of an artwork requires philosophy (Adorno 1984:507)

This transcendental feature of works of art is why we have chosen them as vehicle for critical appraisal of biochemistry/ biochemical engineering which are detailed in the following section. However we recognise (as does McNiff 2008) that this can be both a challenging and intriguing methods for those who are not familiar with it.

4.0 Results - Prototypes of Phytoremediation

Two prototype models were created to explore how organic systems can be enhanced with technology. The first is a scale model of an algal bioreactor that cleans or ‘scrubs’ both nitrates and phosphates from water, to protect fish and aquatic environments. The second is a scale model of phytoremediation for heavy metals, designed on a gravity feed-system, to explore how phytoremediation might be built into architectural systems.

Model 1 – Scale model of a Chaetomorpha Algal BioReactor

In the Age of the Anthropocene (Smith and Zeder 2013) nitrogenous nutrients are everywhere, made possible in part by the Fritz-Haber process for fixing nitrogen from the air (Haber 2002). However, nutrients in excess can also be poisons. Eutrophication from fertilizers to grow crops has led to large dead zones in seawater, where nutrients support toxic algae blooms. This is particularly relevant to the Baltic region in general, as both the river Nemunas and Baltic Sea experience high nutrient loads (European Environment Agency 2012b). On land, excess nitrogen in the soil groundwater can be detrimental to human health, causing blue baby syndrome in infants (European Environment Agency 2012a). However, plants, fungi and algae can be utilized to clean these aquatic systems. As well as using nutrients, forms of algae have the ability to absorb or adsorb heavy metals like lead and cadmium (Holan and Volesky 1994).

This nitrogen cycle also happens on a small scale in aquariums. Urea produced from fish excreta and decomposing food is rapidly converted to Nitrite and then Nitrate by two classes of bacteria, the Nitrosomonas and Nitrobacter. Urea and Nitrite are metabolic poisons to aquatic non-plant life, but also represent nutrient sources for growing plants. Aquatic hobbyists have been using Chaetomorpha (Coral Creations 2014), a beneficial algae that removes both nitrates and phosphates from the water, to scrub water in marine aquariums to protect their fish from high nutrients.

Figure 1. A scale model of a Chetomorpha algal bioreactor. 2015. Installation, Kaunas University of technology. Photo: Lina Rukevičiūtė.

In an attempt to produce a scale model that might alleviate these problems an algal bioreactor was created. The installation consisted of a peristaltic pump, a mesh upon which the algae lay and the alga Chetomorpha, in a plastic vessel recycled from a diamond drill bit holder. Built on improvisation, from locally available materials it was a step 'towards' a bioreactor, but it lacked one segment, the fish making the nutrients – See Figure 1. Rather than ready-made, it is an incomplete prototype. Like other scale models given in this paper this model points to a possible use, and gives a form to it, but they are not yet realised or installed. At the core they represent living technologies, whose functions could be used to benefit the local environment and their inhabitants.

Model 2 – A Scale Model Phytoremediation System using Taraxacum Officinale

Introduction

Model two examines how in a future scenario a resource depleted society may continue to process waste based on environmental solutions. Hence we examined how the interaction of plants, and environmental remediation could intersect in confined areas. The installation was based upon a hypothetical scale model of a phytoremediation reactor scheme. The primary plant that was used for the scheme was Taraxacum officinale, more commonly known in English as the dandelion. The dandelion has traditionally been used as a diuretic, to increase bile flow and appetite, to treat dyspepsia (indigestion), and to treat gastrointestinal ailments (Blumenthal et al. 1998, Yarnell and Abascal 2009). Its application in phytoremediation is quite different however, and based on its properties of hyperaccumulation.

Eco-Semiotic Design Philosophy

The action of perusing an environmentally infused design principle with a semiotic philosophy has been explored in detail by Seif (2010), who argues that “Architects must learn from nature and by striving to embody quasi-natural principles; and while products of design hardly produce natural appearances, they lead to insight into nature” (ibid.: 245). Petrilli (2004: 205) furthers infuses this idea with an ethos apt for the Anthropocene by considering the role humans have to play in how their designs intersect between the natural environment and the other species within it, where the human individual is seen as “a living body interconnected to all other forms of life over the planet.”

Others such as Ireland (2015) directly use biosemiotic concepts as design principles in their architectural works. From this perspective, space is considered as a sign, where ones' physical, mental and lived spaces correspond to the Peircian object, representamen and interpretant (ibid). The reason for connecting different conceptions of spaces in our design to a Peircean framework is that it permits us to move away from viewing space as an abstract concept, and starts to situate it as somewhere within which specific sets of behaviours will happen (Lawson 2001). I.e. how humans as organisms (should or could) function within their environs whilst being cognisant of the damage they cause.

Correspondingly the design processes at work in the installations given in this paper are informed by the phytoremediation processes that occur in nature, while also taking account the actions of human that has led to our period in history becoming known as the Anthropocene. The most advanced design of a phytoremediation system can be found in some of the theoretical schematics produced by Influx Studio (2011). These systems are designed for wastewater treatment, which in a resource depleted world could be of paramount importance, see Figure 2.

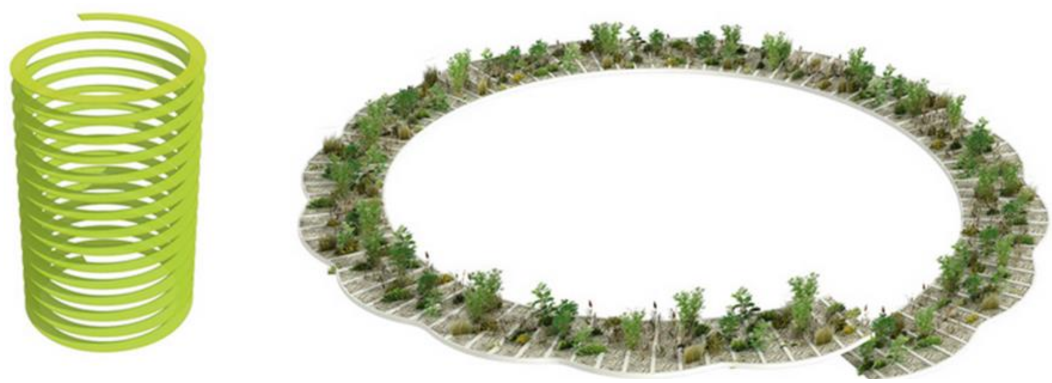

Figure 2. Phytoremediation gravity feed structures, Source: Influx Studio (2011)

In our phytoremediation reactor system, a pollutant is inputted into a selection of plants, which filter out the pollutants, outputting cleaner water or land. Hyperaccumulating plants act like a membrane filtering out the impurities, leaving water that can be used to irrigate crops, or reclaim land for human use. This underlying principle of nature as a transformative system and the biosemiotic conception of space, which connects humans, and their environment are the principles that inspired the choice of our scale models.

Reactor Design

The installation design was based upon a phytoremediation system created by Schröder et al. (2007), which consisted of a multi-stage reactor, where various plant species are utilised to remediate different types of waste. See Figure 3 below.

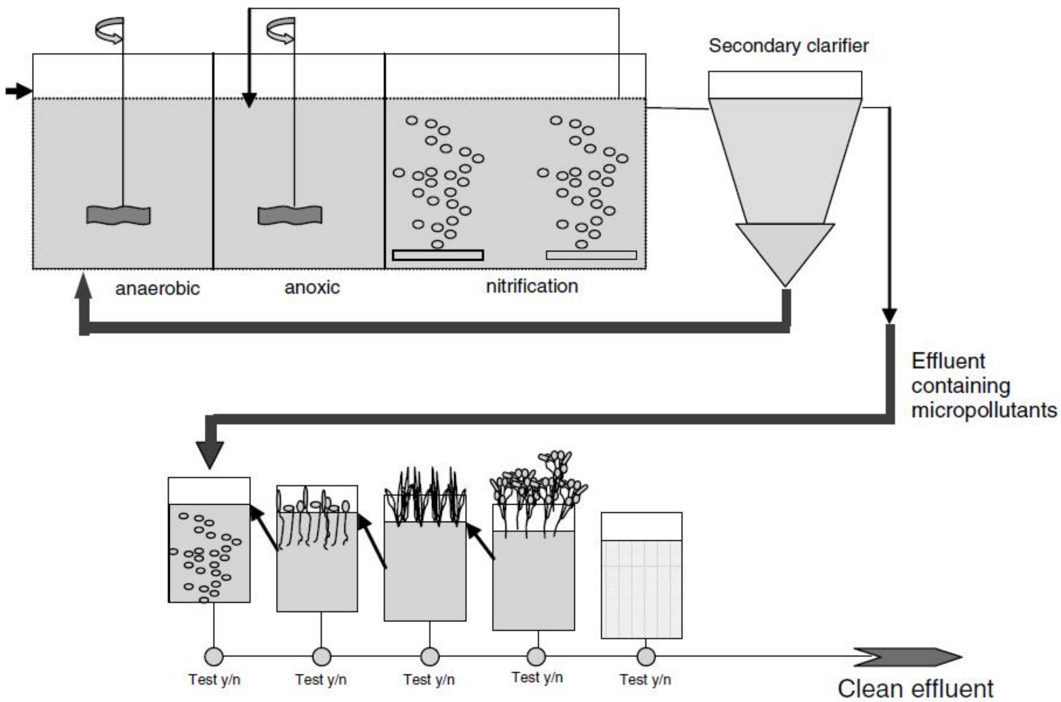

Figure 3. Phytoremediation reactor design, Source: Schröder et al. (2007)

This ingenious design allows the system to match different plants to different contaminants, allowing a site or situation specific solution to environmental problems (see Table 1). This is an established process, extensively used in environmental design, such as in forest gardens where plants and herbs that emit nitrogen and those which fixed it are planted in a symbiotic relationship, known as self-fertilisation (Crawford 2010).

Scale Model

The descending spirals in Figure 2 cause the water as a result of gravity to naturally flow through the plant beds, which as noted previously can contain any number of hyperaccumulating species of plant. The gravity feed can be incorporated into building structures, and other supporting architectures. The scale model of a phytoremediation system was exhibited along with other pieces on environmentally based themes. The scale model was designed to be tactile, so that it could be explored, interacted with and primarily commented upon by the participants at the conference. Due to this the model was altered and developed iteratively throughout the conference based on feedback from participants. See Figure 4 below.

Figure 4. Phytoremediation reactor scheme installation. 2015. Installation, Kaunas University of technology. Photo: Lina Rukevičiūtė.

The installation was constructed from materials available from the local vicinity; the plants used were also sourced locally. Although the piece was not designed as an educational exhibit, the reactors were annotated to highlight some of the different processes that occur in the phytoremediation system. This was done to help the researchers engage participants in debate about the installation as it helped them to refer to certain parts of the installation for the purposes of discussion. Polished glass beads were used as a water substitute, dark orange beads indicated waste water, and transparent beads were used to signify clean water. Gravity feed systems have concordant simplicity with phytoremediation as a concept, in that they both are mechanically simple but biologically complex. This makes gravity feed phytoremediation systems an appropriate fit in the attempt to design a process that could function in times of resources depletion due to human activity.

5.0 Creation of a Functioning Phytoremediation System

5.1 Introduction

The final stage of the project was to construct a dwelling with a working phytoremediation system; specifically we choose to create a decentralized sewer system using a series of septic tanks and a drain-field network, the purpose being to create an autonomous system not dependent on external input. The design was influenced by the feedback acquired about the two prototypes models that were presented in section 4, and idea about the Anthropocene.

5.2 The Homestead

The creation of a dwelling with an autonomous phytoremediation scheme required a site. A 400 m2 site in the suburbs of Berlin was acquired to bring the vision to life. Due to financial restrictions, the dwelling was constructed with reused wooden pallets, see figure 5. A site plan and schematic of the building can be seen in Figure 6.

5.3 The Septic System

Taking the UK as an example, an average domestic home produces 150 litres of water per person every day (Water Wise 2012). This, including discarded food, laundry water, cooking oils and grease flows into a watertight septic tank where it is decomposed by bacteria in our faeces which produce enzymes that aggressively digest and consume sludge, grease, fats, paper and all other organic matter that might block the septic system. Hence our septic system was design to handle all kinds of waste water that has been adversely affected in quality by anthropogenic influence. The contents of the bio-digester are then fed through a distribution box into a leach drain with perforated pipes, which consequently allows the decomposed material to be fed into the plant bed of hyperaccumulating species, in the soil above the leach drain; this is shown in Figure 6. The sanitation system has been designed as a decentralized sewerage system for the management of the wastewater in order to recycle it into a phytoremediation system. Phytoremediation is desirable in this instance partly because a compost toilet in the homestead was not possible due to Berlin city regulations. Traditional septic systems are problematic as it is necessary to fit a pump and we are attempting to avoid the direct use of electricity if possible as it violates the principle of creating an autonomous system, which was part of the underlying approach for this project.

Figure 5 Phytoremediation system being currently implemented in Berlin. Stand October 2015. Photo: Mindaugas Gapševičius

We planned a sewage-treatment facility with three compartments and a leach drain under a crop of hyperaccumulating plants absorbing the overproduction of nitrogen and phosphate. This process is based on the phytoextraction processes mentioned previously which uses plants or algae to remove contaminants from soils, sediments or water into harvestable plant biomass. The homestead building itself can be seen in Figure 5.

5.4 Biochemical Engineering of the System

The sewage-treatment facility designed for the homestead has 3 connected tanks each with a volume of 200 litres, a distribution box, and one drain flow with three leach lines that feed a crop of hyperaccumulator plants- See Figure 6. The wastewater produced in the homestead flows inside the tanks; the majority of the waste decomposes into sewage water, while heavier solids (inorganic solid material, which is generally denser than water) settle to the bottom and forms the sludge layer. Other lighter particles such as organic material, which are generally less dense than water rise to the surface. This is referred to as "the crust" and it can consist of toilet paper, solid waste, grease, etc.

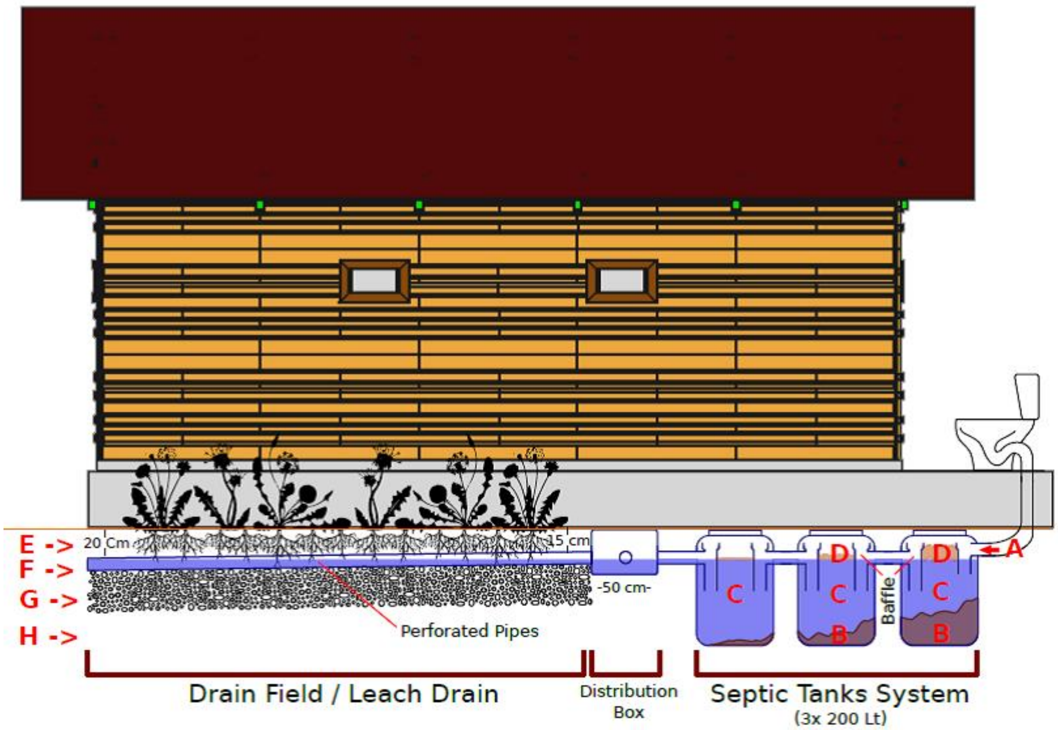

Figure 6. A schematic representation of the Phytoremediation system where A is Wastewater, B Sludge, C Liquid effluent, D Scum, E Top Soil, F Treated water through Perforated Pipes, G Gravel &, H Original Soil. Schematic: Juan Pablo Diaz.

Bacteria naturally found in our digestive systems begin breaking down the organic material in the septic tanks and converting it to liquid form. The decomposed sewage water then flows from tank to tank through the inlet and outlet lines. The baffles were designed to prevent the crust from entering and clogging the lines isolating the surface where the crust floats. From the third tank the rest of the wastewater flows through a distribution box and then into a drainage field – a series of perforated pipes laid below ground in a bed of gravel. The liquid which is rich in nitrates and phosphates leaches out through the gravel and is further purified as it percolates through the soil under the crop of hyperaccumulator plants. The crop planned is one of Taraxacum officinale which grows easily and densely in different conditions and consumes the overproduction of these heavy metals elements.

6.0 Discussion

Perspectives on the thresholds to semiosis have perhaps changed since Umberto Eco (1976) suggested the exclusion of neurophysiological and genetic phenomena as domains of semiotic activity. However, Eco did offer cautionary advice to those delving into the murky waters of protosemiotic activity (ibid). It is the author's hope that we have adhered to this advice and not overstepped the boundaries that exist between biotic and abiotic systems. Kull (2009) indicated that because of the immense variety of sign systems that can exist, one of the key areas that biosemiotics needs to develop is a classificatory scheme for semiotic threshold zones in living systems. Whilst this paper does not offer a classificatory scheme in itself, it does give examples of how different semiosic/semiotic systems interact (Favareau 2015), and not just in organic systems. Our work builds on Deely (1990); Nöth (2001a); Sharov and Vehkavaara (2014) who provide in-depth discussions about the protosemiotic activity and signalling processes that occur at a cellular and sub-cellular level. Previously we cited a question by Kull et al (2011):

> How can anything (e.g., molecule x) that initially does not have a function, obtain a function?

We have explored this issue in relation to hyperaccumulating plants and their how their use has been modified by humans for the purposes of environmental remediation. We also wished to investigate this issue in relation to the creation of transgenic plants. Where by plants are genetically modified by human agents to perform specific functions including the remediation of natural environments. Following the case studies on hyperaccumulation and data given in this paper one such answer could be found in the Phytovolatilization processes of transgenic plants that are manipulated by humans to express MerA and MerB genes in bacteria which help to render methyl-mercury (as found in soil) into a state that is 100 times less toxic (Pilon-Smits and Pilon 2000), see Figure 7.

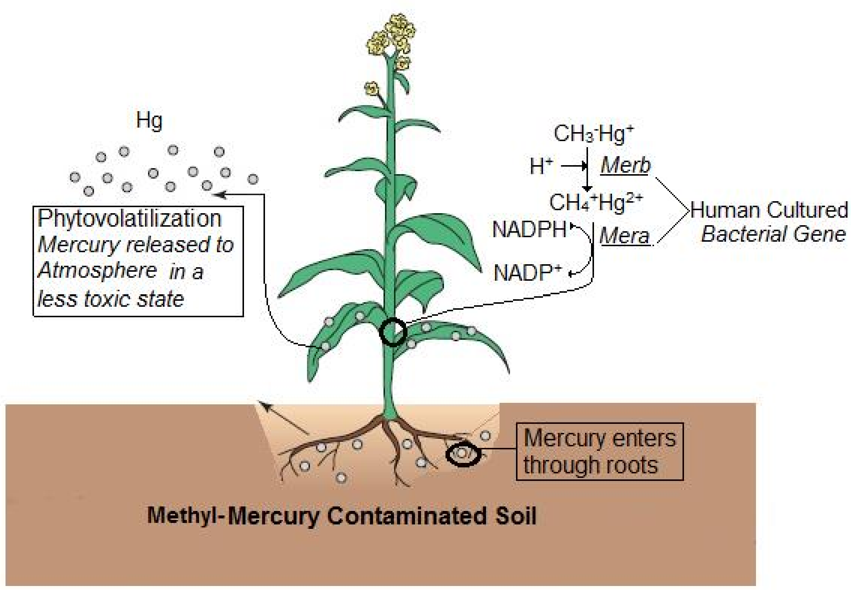

Figure 7. Transgenic plant expressing MerA and MerB cultured by Humans, Image adapted from Pilon-Smits and Pilon (2000).

The process shown in Figure 7 also relates to another question posed by Kull et al. (2011:72), the so-called Uexküllian question: "How is the experiential world (or umwelt) of an organism organized? Or: In what does the world experienced by an organism (umwelt) consist?" Whilst the first part of the question, relates to the sign-mediate experience of life, the answer to the later statement when applied to the experience of plant life in this current epoch is rather less cheering. The world experienced by hyperaccumulating plantae such as Taraxacum officinale is contaminated with heavy metals and other forms of pollutants as a direct result of our anthropomorphic shift into the Anthropocene. In concordance with the other Anthropocene discourses that have been given in this paper, we suggest that humans as semiotic animals (Deely 2003) have an extended hand to play in some existing biosemiotic systems, for example, turning once more to Kawade (1996: 200):

> Every molecule in living systems stands not only in dyadic relationship with its chemical reaction partners but in triadic relationship involving the organism or the cell or its part as the third partner

From a teleological perspective, as Kawade (1996) noted, genetic and physiological systems are not purposive but we would suggest that the culturing of transgenic plants to contain bacterial genes by humans is purposive. As such, hyperaccumulating plants whose phylogenetic properties are a result of teleonomic processes can also contain compounds or elements that have been produced as result of teleological systems, such as the laboratory cultured bacterial genes shown in Figure 7. Hence, when considering issues around endosemotic or protosemiotic systems one should consider the 'human' or teleological effect on biological system rather than analysing a process in isolation of wider influences. By human effect here we are not only referring simply to the subtler collective human actions that change environments within which organisms live, such as eutrophication, oil spills, anthropomorphic climate change and other forms of environmental degradation, but rather the direct and intentional modification of organisms at a genetic and cellular level, such as in the case of transgenic plant species. This appreciation of wider contexts is essentially what Peirce termed suprasubjectivity (Deely 2000), and is the process that underpins a properly triadic form of a semiosis, where a sign:

> linking its subject term to a terminus or object signified as represented to some observer or interpretant, prospective or actual in its subjective being; and which, as a relation, is indifferent to passing back and forth between psychological and material vehicles of conveyance. Thus, while both the sign vehicle and the observer when actual are subjective beings, the sign itself is always and irreducibly suprasubjective. And the "object signified" or significate of the sign is itself always and irreducibly sustained as the direct terminus of a triadic relation regardless of whether it has any subjective being at all as an immediate part of its objective being, its "objectivity", or status as signified (ibid.: 40)

As stated, it is legitimate, then, to consider the human impact on biological process, given that they are not separate from them (in the case of transgenic plants for example) but part of a wider triadic process. Further to this point, while we recognise the valuable distinction between temporal/ non-temporal semiosis, spatial/ non-spatial semiosis or rather between Umwelt[5] and Lebenswelten[6] (Deely 2001) as analytical categories, from a wider perspective the distinctions have a degree of artificiality to them. As Kull (2009:24) related, "Humans possess simultaneously vegetative, animal and cultural semiosis" in both similarly and inversion to this statement we would suggest vegetative semiosis/semiosics in plants is not free of the wider influences of the semiosphere, namely humans. We feel that suprasubjectivity and the role of human interaction mediation in biological systems is a point seldom considered in biosemiotics, perhaps with the exception of the works of Bains (2014).

This is not at all to suggest in any way that bacterial genes perceive humans as sign vehicles, in the same way humans came to recognise cellular organisms through the use of microscopes (Favareau 2015), humans are clearly not sign objects for bacteria. The point is rather to consider how the interaction between the biotic and the abiotic can help in the creation of useful products, even if the semiotic potential is radically different from the transition of Welt to Umwelt to Lebenswelten, as it is vice versa. Kawade (1996) has already highlighted the polysemous and yet contradictory epistemological positions that exist in biology, the work in this paper also suggests that epistemological inconsistency is not always a barrier to utility in creating environmentally beneficial systems. However, it is not without reason that some would argue that the system given in Figure 7 is non-semiotic. However following the statement in (Kull 2009: 17) that: “The simplest semiosis means that relations are in a sequence – and not just in a sequence, but in a recursive sequence – in a circle. [ ] This simple kind type of semiosis can be identified with iconic semiosis.” The authors would contend that remediation systems such as the one given in Figure 7 are a form of quasi-iconic semiosis.

This indicates that the iconic vegetative semiosis can function in a facilitatory/auxiliary manner for abiotic components which are the de novo creations of Homo sapiens in this current epoch. The authors also acknowledge that this is just one element in a wider phytoremediation system given in the paper and how it could be applied in other a biosemiotic contexts would differ. And also, although we suggest transgenic plants can be useful, there is also the issue that the modification of plants to perform particular functions may actually vitiate an understanding of, or sensitivity to, complex open systems.

6.1 Constraints with the Scheme of Work

This paper contains perhaps one main constraint, from an ecological point of view there is a tension between recognizing the dangers of the Anthropocene whilst simultaneously instrumentalising plants systems themselves to perform particular tasks of environmental remediation. This instrumentalization of plants could be considered contradictory to the ethical or normative considerations found elsewhere in the paper i.e. some would argue that eco-capitalism and environmental remediation are not reconcilable ideas. We have however foregrounded this tension by stating in the first instance that this paper was conceived in a rhizomatic sense, without a strict homogenous epistemological position or centre (Deleuze 1980). Designed instead to stimulate debate.

In the context of the work provided we are still far away from being to answer questions about what cultured bacterial genes are doing in each moment? How do they can really “represent” anything? And furthermore, what are the major differences between life and abiota? In this regard what is needed, more than anything, is a look at the Peircian principle of semiotics (such as suprasubjectivity), so that we might argue a more rigorous case for integrating abiota into a protosemiotic framework. Consider, for example in 2001 colloquium organised by Winfried Nöth, The *Semiotic Threshold from Nature to Culture* the question of whether semiotics is broader than both zoosemiotic and biosemiotic was raised:

> Among the agents involved in semiosis, Peirce did not only mention animals, such as ‘a chameleon and many kinds of insects’ (MS 318: 205-206), microorganisms, such as ‘a little creature’ under a microscope (CP 1.269), and ‘plants that make their living by uttering signs, and lying signs, at that’ (MS 318: 205-206), but also intelligent machines, which he describes as being involved in processes of quasi-semiosis. Furthermore, semiosis, and with it also ‘thought,’ occurs even ‘in crystals, and throughout the physical world (CP 4.551), and finally, the whole ‘universe is a vast representamen (CP 5.119).
> cited in Nöth (2001c)

John Deely suggested that threshold debates in semiotics are split between the a conservative position, which broadly represents modern biosemiotics (Krampen 1981) and a more radical factor that is still exploring Peirce's ideas of quasi-semiosis, in which thresholds might be broader than is currently thought:

> The more radical faction (chief among which must be counted Peirce himself) does not quarrel with the inclusion of phytosemiotics under the umbrella of semiotics, but argues that even this extension leaves something out, namely, the physical universe at large which surrounds biological life and upon which all life depends. Heretofore the development of the physical universe as able to spawn and support life has been studied under the rubric of evolution. The radical faction in semiotics today argues that what is distinctive of the action of signs is the shaping of the past on the basis of future events, and on this accounting the action of signs (or 'semiosis') can be discerned even in the rocks and among the stars - a veritable physiosemiosis. (Deely 2000: 3)

Our paper is more in line with the Peircean physiosemiosis position, in that we take on board Peirce's ideas that the universe is perfused with signs, and may even consist exclusively of them (Deely 1997, 1998). It is our admission that our paper is merely here to raise questions and cannot solve the *Grand Vision* as Deely (1994) termed it, to determine how far semiosis reaches into biotic life. We simply hope that we have challenged the reader to think about issues of thresholds in semiotics and in biological systems.

7.0 Conclusion

When one wishes to utilise the hyperaccumulation properties of plants or algal species the basis of the sign processes in plants is of interest. However, the work in this paper aspires to use these protosemiotic processes in the context of the Anthropocene. That is thinking about how the biosemiotic signalling process in organic material can be used for the betterment of the human species, given the increasingly intertwined future that both humans and the planet have. Whilst also acknowledging that the human species needs to contribute to the betterment of the planet itself. To this end, the design of a relatively self-contained, autonomous, phytoremediation system which could function without external input is desirable. From our rudimentary experiments we are able to give examples of how this might function on an everyday level, by applying these processes in the design of a household waste system. Building on the commentary in Sebeok (2001: 68) about the axiomatic connection between the spheres of semiosis and biology, the authors feel that a comprehension of the semiosphere can lead to a better comprehension of the biosphere and ways in which to prevent further degradation to it.

We believe our primary contribution in this area is to give working examples of how the dyadic relationship between organic and non-organic sign systems (or between the biotic and the abiotic) can be integrated and designed to create products that are beneficial to humankind. Humankind in the Anthropocene is not a passive element in this dyad, but represents the missing third element in the systems that we have described. Further work needs to be undertaken to explore how teleological and telenomic sign relationships occur in biosemiotic systems where the mediation of humans is far from passive.

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Endnotes

1. The Anthropocene is a term for the concept that humankind's influence on the Earth's atmosphere and biosphere in recent centuries is so significant that it constitutes a new geological age. It is not yet formally accepted as a geological timescale but rather a way to contextualise the extent of the impact humanity has had on the planet, primarily due to industrialisation.

2. Special additional thanks and credit needs to be given to Matthias Roth.

3. For example, a similar focus can be found in the *Haus der Kulturen der Welt* programme which occurred between 2013 and 2014 in Berlin, or the *Globale: Exo-Evolution* exhibition at the ZKM, Centre for Art and Media in 2015/6 in Karlsruhe Germany.

4. Transgenic plants can be described as plants into which one or more genes from another species have been introduced into the genome, typically using genetic engineering processes, see Kung and Wu (1993).

5. For a further distinction in relation to this term see Danesi (2000: 236)

6. The term Lebenswelt originates in Husserlian phenomenology (Deely 2013), but has been incorporated in semiotics by Deely (ibid). It simply means a human's Umwelt, or the species specific objective world of humans (Bains 2001). It is used to categorically distinguish between the umwelt of human and non-human species.