BOUNDARIES AND FRONTIERS AT BIOSPHERE 2: 1991-1994

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ABSTRACT: This paper examines relationships between conceptual and spatial boundary conditions as they produced knowledge, processes, communication, and frontiers at Biosphere 2 [B2]. B2 created a novel architecture, one that simultaneously addressed symbolic and molecular criteria. The architectural-apparatus of B2 was constructed as a laboratory to house a microcosm of Earth's ecosystem service provisioning processes for eight people, over two year intervals. Over 3,600 species were intentionally and unintentionally entangled within a 'Human Experiment' designed to test eco-technical applications for long-duration outer space colonization. Boundaries were essential to the project's design, construction, and enclosure experiment. They both facilitated and undermined the experiment's success architecturally, scientifically, and culturally while creating inherent tensions through the delineation of edges driven by conceptual boundary conditions, often determined utilizing Ecological Systems Theory and diagramming practices. In the case of B2, the primary boundary manifest as the physical bathtub-space frame building envelope which facilitated unprecedented potential for quantification and categorization of molecules in the gas phase. For B2, this boundary was considered necessary for scientific inquiry during 'The Human Experiment,' and produced intense design, construction, and maintenance challenges. Once complete and sealed inside, an edited and enhanced Earth, shrunk 30 trillion times, began to evolve. Through the demarcation and analysis of B2's boundary conditions and their dynamic qualities, which frequently demanded redefinition, this research unpacks relationships between architectural envelope conditions, transitional spaces, scientific theory, body/organism skins, and biogeochemical processes to reveal findings related to the entangled anthropocentric condition architectural occupies today.

KEYWORDS: Biosphere 2, Boundary Conditions, Anthropocene, Posthuman, Transhuman

BIOSPHERE 2 ENCLOSURE EXPERIMENTS: 1991-1994

In 1990, amidst saguaro cacti and roving bands of javelina, a hybrid construction crew of professionals and a unique group of visionaries raced against the sun's daily trajectory to assemble the tightest building envelope ever constructed. Biosphere 2 [B2] emerged as a stainless steel lined concrete bathtub with space-frame topper, which would enclose a 3.14 acre area containing approximately 7 million cubic feet of air, inorganic matter, and biomass [Dempster, 1999]. B2's first closure experiment, Mission 1, commenced at 8:00 am September 26, 1991 and terminated at approximately 8:20 am September 26, 1993. It:

> ...was designed to operate for 2 years with a crew of eight healthy 'Biospherians' with the aim of supplying the entire food needed for the crew, maintaining a 200 m3 atmosphere with safe levels of trace gases, complete recycle of human and animal wastes, and recycle of water, and a minimum leakage of air... and if it failed any of these aims, to analyze the causes to improve the apparatus. [Allen + Nelson, 1999, 17].
> Functioning simultaneously as a venture capital project for long-duration space colonization, a large-scale ecological laboratory, and a social-ecological experiment, in the end only two missions occurred out of the 50 conceived as a continuous chain of 2 year duration experiments.

During its enclosure missions, B2 operated as the tightest material boundary condition ever constructed at architectural scale. When sealed, it facilitated energetic and information exchange from the sun and digital communications, while exchanging less than 10% of its atmosphere with earth annually, [Dempster, 1994] compared to the Space Shuttle which exchanged 10% of its atmosphere with outer space daily. It created a microcosm of Earth, an energetically open but materially closed system that produced an evolving biogeochemistry that increasingly diverged from Earth's as the experiment progressed. Its interior can be thought of as a molecular economy composed of select components of our planet's matter, in liquid and gas phases, that produced accelerated biogeochemical cycling: "It's small enough that things happen fast...because it's so small, you could see immediate changes" [Alling, 2015].

B2's enclosure demarcated a novel boundary, one that facilitated the measurement of environment according to productivity, and human bodies according to health and toxicity, which the Biospherians' conceptualized utilizing Ecological Systems Theory [EST]. EST, with its quantified flows of energy and matter, shifted the project's units of measurement from surface area to the more refined unit of volume. This 3-D, 'quantum' condition, generated to test the 'The High Frontier' of outer-space through the integrated process of instrument and experiment design, demanded new mappings of flows and devices for data collection and processing, novel hybrid eco-technical programs and infrastructures, and a unique culture of sustainable stewardship.

1.0 DEFINING BOUNDARIES, CREATING FRONTIERS

1.1. The Science of Ecological Microcosms

EST was largely developed in the late 1950's, and once put into practice at the Odum's labs and beyond, began to evolve. The first of its evolutions influential for B2, was originated by the Head of the University of Hawaii's Exobiology Laboratory, Clair Folsome who was 'bottling' ecological samples from aquatic environments across the globe containing "... complete functional suite[s] of microbes together with [water and air]...inside a closed laboratory flask..." [Allen 1990] (Fig. 1). These ultimately became the diagram and model for B2 and its missions. Ironically, the first one was sealed in 1968, one year before Apollo 11 landed on the moon. Folsome's inauguration of the science of closed ecological systems allowed him to quantify, to "...measure oxygen and carbon dioxide levels, study energy flows and visually observe changes" [Allen, 1990]. By doing so, Folsome not only furthered EST, but simultaneously propelled a long trajectory of the study of microcosms, dating back to the Ancient Greeks [Conger, 1922]. Many of these Buchner flasks are now located at the B2 facility and are still living dynamic microcosmic systems.

Based on Folsome's observations, and EST, the Biospherians convened a series of conferences, which furthered the theory and practice of Ecological Microcosms, and simultaneously B2's design. These became incubators for a number of scientists from a wide range of disciplines to further closed-ecological systems ideas such as Harold Morowitz, Walter Adey, and others. Morowitz, a biophysicist, served on B2's Scientific Advisory Committee, and utilized B2 to test his theories related to the application of thermodynamics within living systems. Adey, an algal ecologist, built a variety of experimental aquatic ecosystem microcosms and mesocosms during the 1980's and 1990's at the Smithsonian Institute to test the most efficient photosynthetic systems on Earth. He was put in charge of designing the aquatic systems at B2.

In 1993, less than 2 years after Mission 1 began, Robert Beyers and Howard Odum, officially inaugurated their new scientific discipline by publishing a 500 page volume titled 'Ecological Microcosms.' The book spans theory and practice, utilizes EST diagrams to illustrate phenomena, and contains chapters on aquaria, stream microcosms, terraria and soil microcosms, wetland microcosms, ponds and pools, reefs and benthic microcosms, plankton columns, and thermal and brine microcosms. There are detailed technical drawings of these eco-technical microcosm apparatus along with an appendix entry devoted to "Experiments on the Closed Ecological System in the Biosphere 2 Test Module" [Beyers + Odum, 1993] (Fig. 2). Perhaps most significantly, their work explicitly linked ecological system boundaries to the environments/ apparatus that contained them.

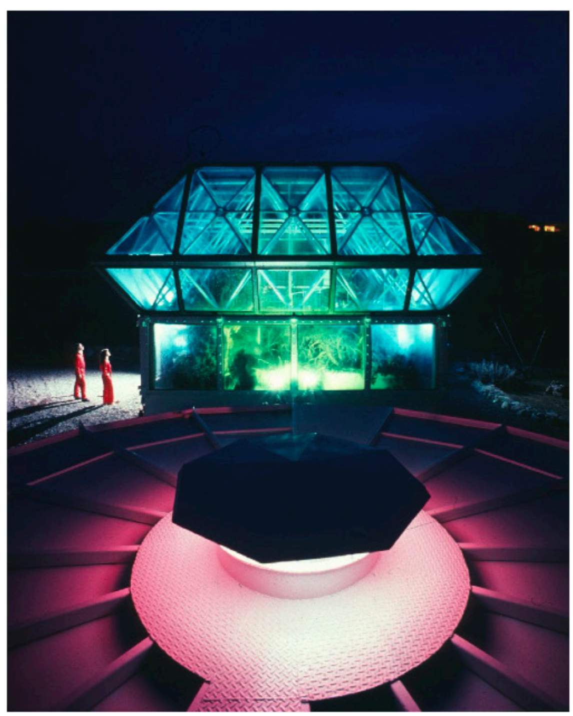

Figure 1: Clair Folsome with one of his experimental ecospheres. Source: (Biosphere 2 archive, University of Arizona)
Figure 2: The Biosphere 2 Test Module, circa 1988. Source: (Biosphere 2 archive, University of Arizona)

1.2. Boundary in Ecological Systems Theory

The Biospherians had tacit knowledge of relationships between resources, productivity, and boundary necessary to choreograph long-duration colonization. They had spent years restoring degraded landscapes around the globe [Allen, 2009], which would later become the models for B2's five wilderness biomes: rainforest, desert, savanna, marsh, and ocean. B2's experimental aims produced a new type of enclosure, a new type of interiorized frontier, which demanded new forms of measurement. Early on the Biospherians' identified the Odum's Ecological Systems Theory [EST] diagramming as critical for accomplishing this measurement, necessary for actualizing their integrated vision. EST developed methods to trace and quantify flows of energy and matter through environments, not just representing them as taxonomies. Howard and Eugene Odum, the founders of EST, conceptualized environments as systems of energy flows, initially through ecological food webs. In their work, they traced ninety-nine+ percent of the energy pulsing through matter on Earth back to its source, the sun, and developed a universal measure of energy, the emjoule unit, which created a solar equivalency for all previous units of energy. The *emjoule* was utilized to specify and calculate energy moving through a system, which first required drawing a clear boundary around the system. Once an appropriate boundary was determined, the energy/matter relationships within that boundary were depicted utilizing three linked methods: a flow diagram which visualized all components in the system and their linkages, a set of equations that quantified the energy movement through time, and a graph of the equation which visualized the relationships between the flows through time.

Through the Biospherians' visionary eyes, this process could not only describe the world, but could also facilitate its redesign. EST's method of diagramming ultimately became the generative design tools of B2. It allowed for existing geographically-based biomes to serve as models for B2 biomes, not "...artificial simulacrum...based on statistically-determined collections of plants..." [Allen, 2009, 162] by facilitating methods for quantification of the ecosystem service provisioning of these landscapes, necessary for their long-term performance and production. It simultaneously became B2's language of inquiry because it was easy for scientists previously unfamiliar with it to learn, and it served to erase disciplinary boundaries, to some extent, by converting them into energetic terms. In the end, it also produced results that the Biospherians living inside would later describe as 'beautiful':

> We had the most perfect nutrition recycling system in that everything at some point went back into the soil. And by the time it was finished in '91, already the biomes were taking form, and you could begin to see how they were going to look and they were starting to mature. So what we moved into in 1991 was a very, very beautiful thing, a very beautiful space [Silverstone, 2015, 10:25-10:55].

1.3. Envelope as Boundary

Because B2's envelope was conceived and constructed as a materially closed by energetically open boundary condition built to operate as an experimental apparatus for 100 years, the quality of B2's envelope engineering, materials, construction techniques, and post-construction commissioning were impeccable. Composed of an underground bathtub style liner of 3 mm thick 'super' stainless alloy Allegheny Ludlum 6XN which lines a concrete slab containing 2.5cm diameter sniffer tubes (installed behind each weld to monitor them for leaks). Capping this bathtub is a glazed space-frame skin composed of approximately 16,000m2 of double pane laminated safety glass sealed within steel tubes, set inside aluminum flame sprayed/powder coated space frames that are double sealed with approximately 30 km of silicone [Dempster, 1999].

Because B2 was so airtight and subject to fluctuating temperatures and humidity, it required additional mechanics in order to keep the laminated glass space frame skin from exploding during sun-filled desert days. So B2's boundary also included the first variable air volume pressure relief structures of their kind, endearingly referred to as *The Lungs*, these domes are attached as appendages to the main structure. Each is comprised of a protective layer that houses a continuous airtight hypalon membrane weighted in the center by a 20 ton aluminum disc. The membrane/disc unit rises and falls as air expansion and contraction occurres, maintaining a relatively constant air pressure inside. The lungs facilitated a combined expansion capacity of approximately 43,000m3, adding about 30% additional volume to the structure when fully inflated. Depending on pressure differentials, as much as 0.5m3 per second of air would move between B2 and the Lungs [Zabel et al, 1999] creating a gentle breeze.

1.4. Boundary Defines Frontier

The history of the relationship between boundaries and frontiers in American culture is rich and entwined within B2's conceptualization of boundary condition, resource management, and frontier. It can be traced back to the 1803 Louisiana Purchase, which almost doubled the American landmass overnight. The acquisition exacerbated problems that Americans' east of the Mississippi had contended with for years: accurate surveying. Of all the methods employed, including triangulation, Andrew Ellicott's proved to be the most accurate by employing an equal-altitudes telescope for star and moon observation [Linklater, 2007]. It was only through the view off the planet that precise Cartesian measure on the planet's surface was established. (Ironically, the Biospherians' view off the planet, to Mars, also reflects this clearer conception of the Earth from the vantage of outer space.) Years later, one of the architects of B2, Phil Hawes, would re-contextualize this relationship between boundary and measure on the Earth's surface through understandings of waste in the environment. He wrote

> A human in Earth's biosphere cannot see to the boundary of the biosphere—or even the bounds of the biome or eco-region he or she is in. Biosphere 2 and even smaller ecosystems, such as the Biosphere 2 Test Module, put the boundaries of the whole and the relation of the parts into a clearly visible paradigm or model that hopefully delineates the ethics and necessity of an ecological lifestyle for inhabitants of a biosphere [Nelson, et. al, 1990, 66].

Both surveying [which is concerned with quantifying 2-dimensional surfaces, and B2, which is concerned with quantifying 3-dimensional volumes] utilize forms of visualization to conceptualize earth scales and processes within human scale. This act of visualization, pared with quantification, proved essential to the visioning and design of B2.

The Biospherians were not unprecedented in their contextualization of resources as contingent with other, three and four dimensional methods of quantifying the environment. The climate of western North America seems to engender similar conceptualizations despite the fact that pioneers of European descent often saw western lands as endlessly resourced during their westward expansion. Inevitably this proved devastatingly inaccurate. Even prior to Ellicott's time, select westerners had clear conceptualizations of the pressing issues unique to life on their side of the 100th parallel related to resource availability, and the disconnect between their landscape and the Rectangular survey overlaid upon it, that was developed in the East. When the first Americans of European descent arrived in Mexico, they found that Mexicans had adopted the Spanish tradition of measuring the land via fanega,"...a measure of about 2 bushels—meaning an extent which two bushels of wheat will suffice to sow" [Gregg, 1845, 152]. A measure of land based not on surface area alone, but on a relationship between surface area and agricultural productivity. Major John Wesley Powell's report from the field dealt directly with water resources in the West's arid environs,

> ...plead[ing] for adjustment of land laws to fit geographical conditions, explaining that in a region where water, not land, was the major resource, different regulations were essential for survival [Powell, et. al., 1879].

Even at the end of the century, Woodrow Wilson's lament in the Atlantic Monthly clearly demonstrates that that Americans had yet to learn the lesson:

> We have left the manner of boundaries to surveyors rather than to statesmen, and have by no means managed to construct economic units in the making of States. We have joined mining communities with agricultural, the mountain with the plain, the ranch with the farm, and have left the making of uniform rules to the sagacity and practical habit of neighbors ill at ease with one another [Wilson, 1897].

1.5. Boundary Defines Enclosure

As the Western frontier's edge continued on its march, the Rectangular Survey's lines transitioned from an edge facing an unknown, to divisions between known entities which demarcated rectangular enclosures. When barbed wire arrived at the frontier in the 1880's which facilitated the physical manifestation of enclosure through the extrusion of fences that chopped the once open range. Fences removed resources from the common pool, re-casting them as private goods. This facilitated an inward turn, farmers and ranchers began to understand their properties as semi-autonomous, closed-loop productive landscapes, similar to their British counterpart, the Estate. But the homestead was more than a landscape of production, it was also a cultural core, and as the Western Pioneers turned inward they brought their values and habits with them.

> Pioneers welcomed wild country as a challenge. They conceived of themselves as agents in the regenerating process that turned the ungodly and useless into a beneficent civilization [Nash, 1967, 43]

But the freedom of the ever expanding edge encountered the limit of the Pacific Ocean, which proved both a spatial and psychological limit. By the early twentieth century much of America's western land-grab was complete, and the violence of the frontier had largely turned its face inward, to a new frontier, the dense spaces of socio-economically hierarchied urban cores.

Post two World Wars and two decades of prosperity, the U.S. was anxious for a new, virgin frontier, one that would ultimately prototype B2. In September of 1962, from within Rice University's stadium, J.F. Kennedy cracked open that next frontier by claiming that

> ...what was once the furthest outpost on the old frontier of the West will be the furthest outpost on the new frontier of science and space. Houston...with its Manned Spacecraft Center, will become the heart of a large scientific and engineering community [Kennedy, 1962].

Thus the race to the Moon was launched, defined by the critical need for boundary layer between human life-support system and the violent void of outer space. While the short-term moon missions would be accomplished eight years later, they are relatively straightforward operations compared to the long-duration, remote space colonization that B2 was prototyping.

1.6. Living within the Diagram
Once fluency in the Odums' Ecological Systems methods was established, the Biospherians were choreographing the creation of their *new oikos*, their new house, with a host of ecologists, biologists, engineers, architects, and landscape architects collaborating on the design and construction of seven fully operational biomes. Within B2's autonomous eco-technical ecosystem service packed mini-earth arc, a new species of frontier was born, an applied science of non-geographically situated environments where chemical cocktails cycled rapidly. This, in combination with the ever-present gridded glass megastructure space frame produced transference and indeterminacy between interiority and Biosphere 1 'outside' [Lavin, 2004], and a dream-like alternate reality that chemically morphed space, time, and explicit boundary conditions somewhat analogous to the hypnotic quality of Folsome's sealed Buchner flasks. His self-organizing, sustainable ecologies not only furthered scientific inquiry, but also predated, and resonated symbolically with Apollo 17's first photograph of the sphere of the Earth surrounded by the void of space, which ultimately unleashed a new holistic paradigm. Folsome's flasks became functional models, and simultaneously symbols of Earth's materially closed system. Ultimately, they became the model for B2, the largest materially closed, energetically open mega-structure ever built.

With the conceptual model in place, EST's tripartite method of diagramming and budgeting ultimately became the primary generative design tool of the interior, which would later contribute to the production of a scripting of the behaviors of the building's inhabitants. Throughout the evolution of B2's eco-technical architecture and landscape, ESTs functioned as design predictions, as scientific depictions, as scripts, 'Rosetta Stones' of communication, and as signifiers of co-production. Largely, EST diagramming facilitated whole-systems thinking and interdisciplinary design across the range of experts working on the project.

Ultimately, because the Biospherians' inside during Mission 1 contributed extensively to the design process, this research argues that the knowledge they accumulated from the design phase significantly influenced their modes of habitation, environmental management, and research once inside. They had to tread between idealized conceptual mappings of EST energy/matter flows, and the realities of material frictions, and between cognitively dissonant modes of operation as posthumans and transhumans, which had significant ethical and procedural implications. These were particularly evident as they grappled with realizing anthropocentric motivations inherent in Vladimir Vernadsky's environmental ethic of Noösphere [Vernadsky, 1945], which the Biospherians' adopted as a guiding principle and diagrammed into their overall microcosmic system (Fig. 3).

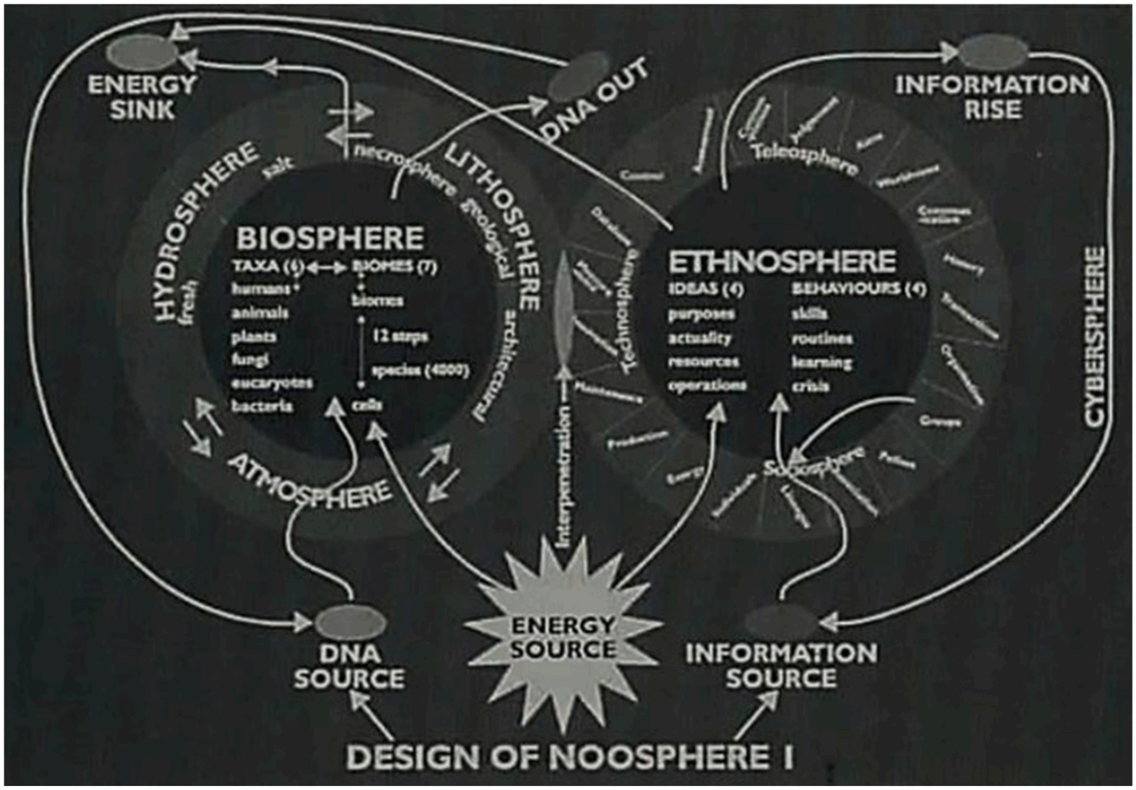

Figure 3: Diagram of relationships between the Biosphere and the Ethnosphere that produce Noösphere. Source: (Allen, 2009)

EST also facilitated a more intimate knowledge of molecular and energetic exchange, which caught all of B2's species within a cybernetic web of co-production and 'unnatural' sites of agency. The Biospherians' were not completely unaccustomed to this habit of mind, their intentional community had a history of structured practices of tacit knowledge acquisition, largely based on theatrical performance, the rigorous production of crafts, and ecological restoration [Reider, 2009]. EST's synergetic logic, methods, and nomenclature resonated with the Biospherians' modus operandi, and further facilitated their deep engagement with the experiment through simultaneously visual, quantitative, and integrative modes of design, knowledge production, communication, and lived-experience.

2.0 BOUNDARY BLUR

2.1. Biospherian Co-Production: Bodies and Minds

> The relation is the smallest unit of analysis, and the relation is about significant otherness at every scale. That is the ethic, or perhaps better, mode of attention, with which we must approach the long cohabitings of people and [other species]. [Haraway, 2003, 24]

Because the Biospherians had co-created the design and construction of B2, which they came to endearingly refer to as the '9th Biospherian' once the Mission 1 crew of 8 was sealed inside, they leveraged an immense intellectual knowledge of their environment. While the rest of their team looked in from the other side of the glass, and through electronic communications, the Biospherians inside were experiencing unique embodied relations with the other species, and the larger biogeochemical cycling.

> We could traverse the closed system, touch the space frame and cement floor, remember how the biomes were created, and visualize the entire world we lived and breathed for 2 years. This provided powerful insights about Biosphere 2 that would not have been fully possible if we did not have the opportunity to participate in its design and construction...Because of this, we were there to learn about the system we had created and let the complex nature of this coherent closed system teach us about its dynamic cycles. It was an unprecedented 2-year experiment between the observer and the observed due to the length and comprehensive design of the experiment. The observer was part of the experiment, the cooperative manager, observing it as part of a process [Alling, et. al., 2002, 74-5].

Simultaneously, as with many complex designed systems, the project was continually fraught with parallel tensions between alternate perspectives. In this case, they often manifest as disjunctions between ideological motivations and environmental realities. While the privileged view, described by Alling above, was deeply satisfying, the same EST diagrams, which facilitated this view through its inscription within the mind's-eye of the inhabitants, ultimately influenced their behaviors. This created significant critical tensions related to the objectivity and ultimate validity of the scientific experiment.

> We knew how Biosphere 2 was designed, where its boundaries reached, how finite its resources were, and in what ways our daily actions impacted this miniature world. In time we learned how to live with this evolving system, and become stewards of its well being. This experience brought a shift in consciousness, similar to the ones the astronauts experienced, we became part of this unique, manmade biosphere. Our health and well being was synonymous with the health of Biosphere 2. [Alling, 2015, 2:00-2:32]

The Biospherians were split between their embodied experience, the roles they were to play as scripted by EST diagram flows, and the objective mental space they were expected to maintain as scientists. As it became more and more difficult to disentangle the many roles the Biospherians assumed within the experiment, and the exhaustion resulting from intense manual labor on a low-calorie diet accumulated, the intellectual, emotional, and spiritual *boundary-wall* between the humanities and the sciences within them began to dissolve. With it, the Biospherians inside were stripped of their power as independent pioneers within their frontier, and within the scientific community they had worked so hard to assemble. They were increasingly subsumed under the control of their management, their Scientific Advisory Committee, and the media outside.

2.2. The Cyborg and Companion Species

This research argues that they had been conceived as, and had become cyborgs, but in the process had actually shifted into a more emotionally entangled relationship with the 9th Biospherian, thereby aligning themselves as companion species in addition.

> Cyborgs are 'cybernetic organisms,' named in 1960 in the context of the space race, the cold war, and imperialist fantasies of technohumanism built into policy and research projects...Telling a story of co-habitation, co-evolution, and embodied cross-species sociality, [the Companion Species Manifesto] asks which of two cobbled together figures—cyborgs and companion species—might more fruitfully inform livable politics and ontologies in current life worlds. These figures are hardly polar opposites. Cyborgs and companion species each bring together human and non-human, the organic and technological, carbon and silicon, freedom and structure, history and myth, the rich and the poor, the state and the subject, diversity and depletion, modernity and postmodernity, and nature and culture in unexpected ways. Besides, neither a cyborg nor a companion animal pleases the pure of heart who long for better protected species boundaries and sterilization of care. [Haraway, 2003, 4]

Both the Biospherians and Haraway have concluded that "art and engineering are natural sibling practices for engaging companion species." [Haraway, 2003, 22], to dramatic effect. But technocratically driven design doesn't necessarily produce empathy and ethic, necessary for achievement of one of the ultimate goals of the Biospherians: to prototype not only eco-technical apparatus, but also manifest a culture of environmental ethics that:

> ...produc[ed] new understandings for artists, philosophers, scientists, explorers, managers...and even mystics to raise their disciplines to new levels of integrated complexity that can help create new cultures and strengthen old cultures...to transform Homo sapiens into a creative collaborator with biospheres, rather than a parasite weakening the host. [Allen + Nelson, Space Biospheres, 55]

During the missions, the Biospherians may not have fully understood the implications inherent in the creation of the deep relations [as simultaneously the smallest unit of analysis and as emotional entanglement] they were structuring. Not only were the mission's inhabitants:

> "Biological organisms...becom[ing] biotic systems, communication devices like others. There is no fundamental, ontological separation in our formal knowledge of machine and organism, of technical and organic...one consequence is that our sense of connection to our tools is heightened." [Haraway, 1984, 177-8].

But they were collapsing into cybernetic systems with their environments and the experiment, which rendered them blurry boundary objects that susceptible to increasingly and exceedingly fragile states of existence. Tensions between *landscape*, *labscape*, *demonstration*, and *domestic* space inside B2 were palpable; a new species of internal frontier, visible from all sides within B2's glass space frame.

While this completely constructed synthetic environment produced a laboratory capable of generating a

> …full spectrum of activities involved in the production of knowledge. It showed that scientific objects are not only 'technically' manufactured in laboratories but also inextricably symbolically and politically constructed [Knorr-Cetina, 2009, 143].

Within B2's entirely synthetic space, it was impossible for the Biospherian scientists to "…remain stable individual entities that are separated out from other objects in the laboratory" [Knorr-Cetina, 2009, 146]. Instead, at any given time, some of their features may be coextensive with those of objects, coupled, or they might 'disappear,' as individuals altogether. Because of B2's undeniable "…reconfiguration of the natural and social order…" [Knorr-Cetina, 2009, 142], the space inside cannot just be understood as an improved natural order, or society, but must be seen as a highly controlled "…'upgraded' social order…" Knorr-Cetina, 2009, 146] within a laboratory context. The Biospherian's experiment was deeply entangled, in part because their *Labspace* existed somewhere between the programs of a large lab-bench, their life-support system, and their 'home.' Their rhetoric and representational strategies for multiple diverse audiences, (including themselves) were multivalient, ranging from quantitative analysis of sensor data to paintings to conceptual films, and very specific to their specific circumstance.

It is possible to unpack how components of their particular mix of species, technologies, bodies, and matter/ energy evolved or co-created, and contrasted their localized condition of situated data collection with their more basic-science driven desires for universalizable data. While long-duration eco-technical space capsules may be reproducible and optimizable in theory, in reality they are each very specific entangled environments, or superorganisms, that diverge once enclosed, and evolve into their own specific socio-technical ecologies. Knorr-Cetina describes how comprehensively this phenomenon operates within a scientific laboratory, where it appears there is less entanglement between scientists, environment, technology, culture, and experiment:

> …ontologies of organisms and machines that result from the reconfiguration of self-other-things [are] implemented in different fields, the use of 'liminal' and referent epistemologies [are used] in dealing with natural objects and their resistances, strategies of putting socially to work through the erasure of the individual epistemic subject and the creation of social 'superorganisms' in its place, or the use of equipment as 'transitional' objects. [Knorr-Cetina, 2009, 158].

Ultimately at B2, this resulted in a new frontier of science, a techno-quantum space where objective measurement could not be qualified as such without a situational scaffold; a scaffold that was equally in danger of collapsing. Ecological systems diagrams, with their understanding of enclosure as a critical component of the energy budgeting process, inherently fold identifiable components of this situational scaffold into their forms of measurement, but only as long as their boundary conditions remain intact. Once "…the sign and the flesh are one" [Haraway, 2003, 17], the boundary dissolves, and the production of objective science is rendered impossible.

But is this a problem, or has it been just a less acknowledged reality of living while questioning all along? And what are the implications for the design of resilient, long-duration environments in the age of the Anthropocene, the Capitolocene, and the Chthulucene? [Haraway, 2016]. Arguably, today we all operate as cyborgs, and are therefore subject to risks born of political mishandlings of agency in relation to indeterminacy, and their unintended consequences. As designers working from within entangled systems, tools like EST diagramming are powerful frameworks for mapping relations and locating leverage points within systems. But it is only at the point when one can see the system, by first constructing it, that one can then view how it falls short as the boundaries upon which it was based dissolve.

> "Lacking symbolic mastery of the schemes and their products—schemes which they are, products which they do—the only way to which agents can adequately master the productive apparatus which enables them to generate correctly formed ritual practices is by making it separate.48 This is what the observer is likely to forget, because he cannot recapture the logic immanent in the recorded products of the apparatus except by constructing a model which is precisely the substitute required when one does not have [or no longer has] immediate mastery of the apparatus.' [Bourdieu, 1977, 123]

A REHEARSAL OF THE ANTHROPOCENE?

The same year that Apollo 11 landed on the moon, John McHales' "The Future of the Future" was published [McHale, 1969], which laid out a deterministic view of the technological path to space colonization. Less than a decade later, 'Space Colonies' had captured the American imagination as evidenced by the publication of "The High Frontier" [Gerard K. O'Neill] in 1976, and "CoEvolution Quarterly's "Space Colonies" [Stewart Brand] appeared the following. The new frontier had been identified. Now it was just waiting for pioneers, in this case, to generate the territory from the void of space as three-dimensional envelopes containing human life-support systems. B2's enclosure experiments prototyped that generation process, which has seen another recent uptake with SpaceX, Mars 1, and Bezos and Musk. While the colonization of the High Frontier has not proceeded as the predictions of fifty years ago forecast, B2's experimental apparatus has allowed us to draw more intelligent conclusions about our relationship to Biosphere 1 [Earth] and ourselves as co-constructive agents within its enclosure.

Yet enclosure created unique challenges for the eight Biospherians locked inside, who were not only the inhabitants and laborers that kept B2 systems operational, but also data collectors/ analyzers in the traditional laboratory sense while simultaneously acting as sensor/ actuator units themselves, feeding back into their dynamic environment. They became something more than just human, they became embodied flows, pawns, for better and worse, contained within a simultaneous ecotopia and dystopia of risk and external control, as we may expect other pioneers who follow their path might.

In certain respects, B2 can be understood as an early rehearsal of today's anthropocentric experimentation in sustainable and resilient performative architectural design. Our biosphere's (Earth's) current condition is operating very much as a semi-quantified experiment minus a separate control Earth, for comparison. With the advent of ubiquitous computing and smart buildings, we, like the Biospherians, have been subsumed into the cybernetic system.

> "Clearly, cyborgs—with their historical congealings of the machine and the organic in the codes of information, where boundaries are less about skin than about statistically defined densities of signal and noise...cyborgs raise all the questions of histories, politics, and ethics that [other species] require. Care, flourishing, differences in power, scales of time—these matter for cyborgs. For example, what kind of temporal scale-making could shape labor systems, investment strategies, and consumption patterns in which the generation time of information machines become compatible with the generation times of human, animal, and plant communities, and ecosystems?" [Haraway, 2003, 21]

We have rendered ourselves fragile because we have destroyed the possibility of experimenting objectively, as if we ever had more than a false pretense of that possibility. There is no 'other' Earth that can be used as an experimental 'control.' Like the Biospherians, we are designers of the built environment designing and experimenting in situ, in real time. In the case of B2, this produced novel tensions between space as model, versus space as experiment, versus space as life-support. For us, unlike the Biospherians, we are not operating from within a largely command-control style of governance, and we have no globally agreed-upon coordinated script, despite the numerous intergovernmental summits on climate change of the last decades. This situation raises serious debates over the contexts [especially when they are understood to be entangled] of laboratory spaces, fieldwork sites, spaces of resource production, and spaces of habitation. This form of experimentation has proven highly problematic in relationship to scientific method[s], and can render experimental results difficult to interpret, yet, historically it has played a significant role in the ecological sciences, and certainly within the design and engineering disciplines. Because of this, it may be possible to reconcile the situation, but not likely with methods we have historically deployed. If anything, it begs designers to become more versed across a broad range of knowledges, so that they might better understand boundary blur and its implications. Asking applicable questions that frame our overarching goals as environmental designers, while developing sophisticated abilities to design with their implications, may be the greatest service we can provide. In:

> ...understanding how things work, who is in the action, what might be possible, [we can better understand] how worldly actors might somehow be accountable to and love each other less violently. [Haraway, 2003, 7]

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