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96TH ACSA ANNUAL MEETING
MARCH 27 - 30, 2008
HOUSTON, TX

Tracing an Architectural Lineage Backwards + Forwards From *Silent Running*

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"Conservation Pledge:
I give my pledge as an American to save and faithfully to defend from waste the natural resources of my country – its soil and minerals, its forests, waters and wildlife". [1]

This wishful statement adorns the wall adjacent to Lowell's bunk in the Valley Forge space station. Lowell, his three crew-mates, and a small support staff of "drones" tend the station and their precious cargo: six separate and sealed biomes of diverse flora, fauna and climate. The scene is Douglas Trumbull's low-budget eco-sci-fi film *Silent Running*, released in 1971. The director, a rookie, had gained his experience working on the special effects for Stanley Kubrick's *2001 - a Space Odyssey* and *The Andromeda Strain*. That experience inspired Trumbull to create a different kind of futuristic film which would be "human and real", without the hygienic portrayal of humanity and machines as in *2001*.[2] The film, in no subtle way, places the quest to conserve the ecosystems at the center of the plot, and makes a martyr of the main character, Lowell, who ultimately chooses to destroy himself and the main ship in order for the last biome, the forest, to survive under the tender care of Dewey, the Drone.

This paper examines the links between *Silent Running* and built works related through [1] plot/project agenda; [2] greenhouse iconography and/or morphology; and [3] available materials and/or technologies. The constructed realities preceding and following Trumbull's film will include the Osaka World Expo of 1970, Richard Buckminster Fuller's Missouri Climatron [1957], the Biosphere II [1989] and Sir Nicolas Grimshaw's Eden Project in St Austell, England [2000]. Beyond similarities and differences in project intent, iconography and material/technique, lies the question of how attitudes about the environment and the making of these plant habitats, on earth or in space, has changed?

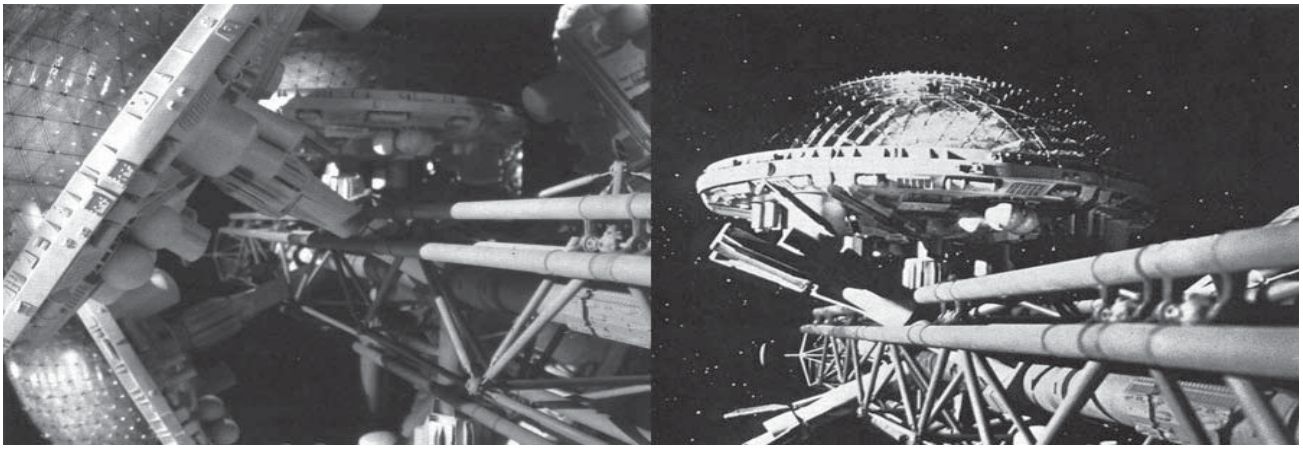

Fig 1

SILENT RUNNING, SATURN ORBIT

> "On this first day of a new century we humbly beg forgiveness and dedicate these last forests of our once beautiful nation to the hope that they will one day return and grace our foul earth…". Anderson [3]

The film's plot originated with an idea about a man who finds himself alone in deep space as a result of some crisis, accompanied only by drones. This organically evolved into the specific story of Freeman Lowell, his human crew-mates, the Drones, and the Valley Forge's precious cargo. We learn early in the film that the earths' citizens have attained a state of peace, free of poverty and illness, but in so doing have somehow rendered the earth a toxic, barren place, devoid of all other living species - so toxic and barren that all that remains of other life forms is contained in the biomes that have been shipped into space, for preservation. These diverse "natural" habitats are little appreciated by Lowell's human crew-mates who prefer the manufactured nutrients over his home-grown melons. And when the orders are given to abandon the mission to maintain the gardens, without flinching, Lowell's mates proceed to nuclear destruct the gardens. Inadvertently at first, Lowell does them in, in trying to prevent one from planting bombs in the forest; the other two are jettisoned along with one of the doomed biomes, exploding in a red ball in deep space. Thus Lowell finds himself wounded, alone with three drones, and one remaining bio-habitat to salvage at all cost.

To make the film on the low budget Universal Studios provided, Trumbull set up the entire film's production on a decommissioned aircraft carrier, called the Valley Forge, after which he'd name the fictional space-ship. This would be the production office, scene shop, and location for all of the shots, minus one set. In total, the film presents four spatial experiences: the main spaceship chambers and corridors, the large earth storage room, the spaceship against the cosmos, and the bio-habitat interior. To transform this aircraft carrier's interior into a more futuristic spaceship, injection molded plastic surfaces and thermo-, blow-, and vacuum-formed sheets were applied to nearly all the walls and doors of the vessel. This was accomplished with a hefty donation of plastic polystyrene sheets from Dow, who felt that their support of this film might improve their agent-orange smeared reputation. Large polyhedral plastic containers, which we discover to be the containers of fertile soil, create the atmosphere for the storage room which the characters cross to get to one of the bio-habitats. Along the way, the Dow logo is ironically ever present.[4]

The primary space to the film's plot are the bio-habitats - six distinct ecosystems, transported by each of the three space ships on this mission. The Valley Forge carries the Alpine, Desert, Tropical, and three other environments which go un-described but are seen in exterior shots of the space ship. Looking for examples of built bio-habitats for set ideas, Trumbull discovered the Missouri Botanical Garden's Climatron- a Buckminster Fuller "terrarium /rainforest inside a dome, (with)

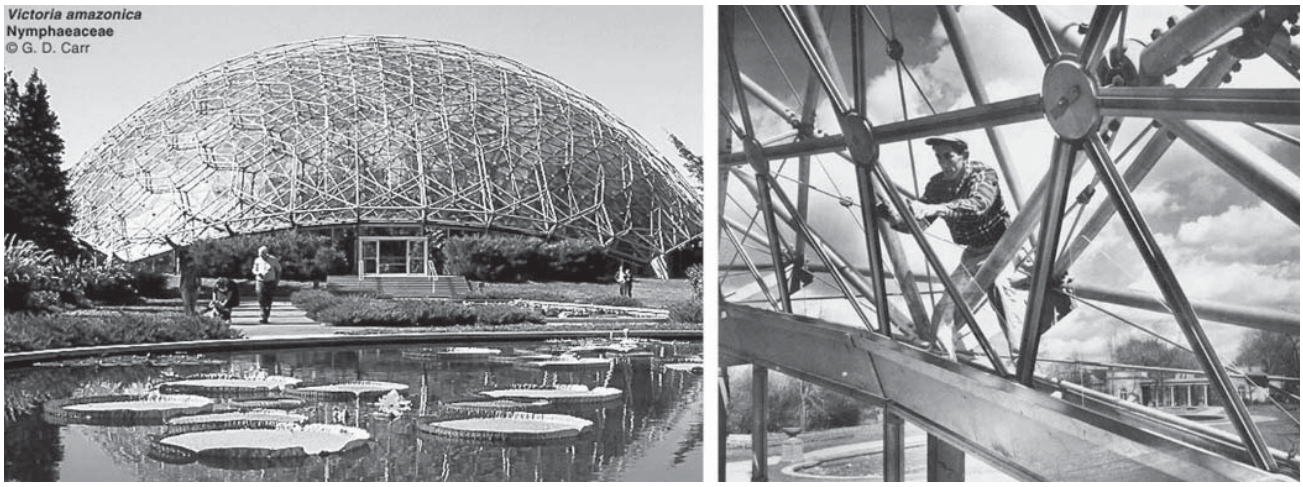

Fig. 2

waterfalls and rocks, trees and plants." Shooting on location would have been ideal, but beyond the budget. Ultimately they simulated three bio-habitats by combining projected still photography of a model dome for the background behind the actual garden set which the crew assembled within an unoccupied airplane hanger. A technique called "front projection" would allow the 2-D photo background and 3D foreground and action to be combined without costly post-production work.[5]

The simulated bio-habitat structure was directly inspired by Fuller's Climatron, where a geodesic structure of aluminum rods and nodes surrounded a clear acrylic enclosure.[6] In the film, this structure was simulated with three layers of copper wire laced through two-foot diameter blow-formed plastic hemispheres.[7] In addition to plastic being the critical set and prop construction, it was also the material that allowed the "safe" overhead enclosure of the Climatron. Six of these mini-climatrons were fabricated and cantilevered in a cluster around the main truss of the space-ship model; each of these represented an isolated, self-sustaining biome under its own, clear, geodesic dome.

WORLD EXPO 1970, OSAKA, JAPAN

The form for the overall spaceship, of a truss with discrete objects attached to it, was largely inspired by the Expo Tower, designed by Kiyonori Kikutake, for the 1970 Osaka Expo.[8] Peter Blake, in his review of the Expo, referred to Kikutake's tower as being "straight out of Cape Canaveral, via Archigram."[9] Kikutake's tower organized clusters of small polyhedral viewing capsules around a slim space-frame mast. The steel ball and strut frame made the structure appear to be expandable. Other pavilions, such as Kurokawa's Takara "Beautilion", more blatantly communicated an open-endedness and expandability through exposed connector joints and an overall irregular silhouette. In the "making of" film, Trumbull makes no attempt to hide his fascination with the Kikutake tower's form and the ideas of metabolic growth behind it. To situate the work of Kikutake and his colleague Kurokawa at that time, these two were the emerging generation of Japanese architects, building what their Archigram contemporaries only dreamed of. The Expo 70 globally exposed their ideas for an architectural 'Metabolism', "a biological analogy meant to replace the

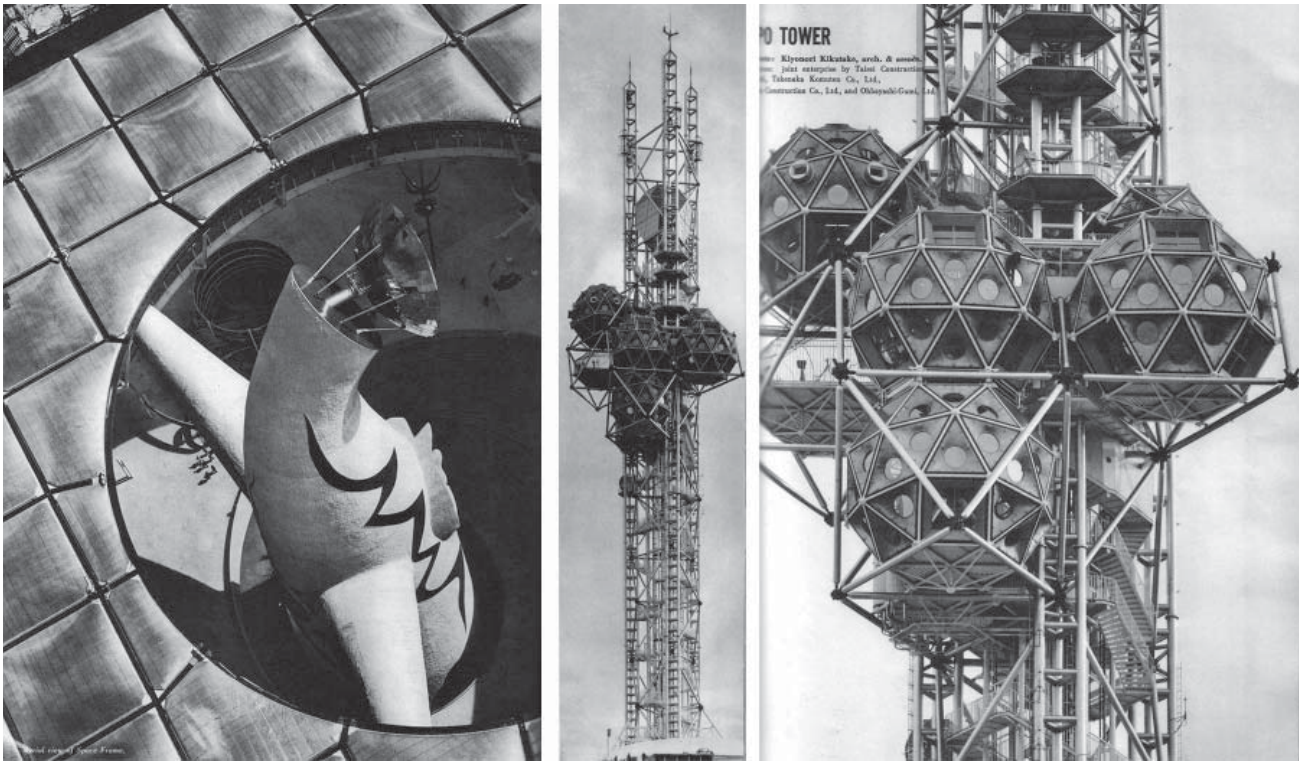

Fig. 3

mechanical analogy of Orthodox Modernist Architecture. It compared buildings and cities to an energy process found in all life: the cycles of change, the constant renewal and destruction of organic tissue."[10]

This fit well with Trumbull's humanist and anti-mechanistic agenda for the film. Given the growth and adaptability agenda of the Metabolists, their language largely employed systemic and geodesic principles, clip-on and plug-in elements. Materials could be expendable, replaceable, with varying cycles of obsolescence. Trumbull's crew "photographed (the tower) extensively, studying its geometry and architecture."[11] Based on these studies of the structure, the film-crew set about making a model of the Valley Forge spaceship, a 26' long space frame of nodes, balls and connectors, with Kikutake inspired polyhedral capsules, distinct Bucky Bio-domes, and a stealth-ish mission control inserted into the extreme end of the frame.

BIOSPHERE 2, ORACLE, ARIZONA 1984-93

Fast-forward approximately ten years, to the Institute of Ecotechnics Seventh [Galactic] Conference in Provençe, France. In attendance: Buckminster Fuller [Synergist par excellence], Lynn Margulis [microbiologist], Phil Hawes [Taliesin-trained architect], John Allen and Margret Augustine [Inst. of Ecotechnics ring leaders] and many more.

Phil Hawes addressed the attendees with the question: "Why not look at life in space as a *life* instead of merely travel?… why not build a spaceship [earth] like the one we've been traveling on – along with all of its inhabitants?" He presented his model of the *Galactica*– a plastic globe, of quasi De Stijl-ian influence, inside of which, he explained, space travelers would enjoy "gardens, housing units, a jogging track, research laboratories, and a pool beneath a waterfall." The presentation prompted Fuller to pose the catalytic challenge: "If you don't do it, who will?" Responding to Bucky's challenge, the core of eager synergists set off to test the dream of self- sustaining biomes in space, with the backing of billionaire Ed Bass.

This was the beginning of the Biosphere II project. On sun-soaked land just north of Tucson, Arizona, the team prepared their plans to build the most sealed environment yet constructed on earth, within which they would hold a two-year experiment. Could the diverse plant biomes and their microbial, animal and human inhabitants all survive AND be healthy within this closed system? Could this be a model for extended space exploration and even colonization?

The structure that sheltered, or rather hermetically contained, this experiment, was developed between Hawes, Augustine and a slew of consultants in every domain. Augustine, in her Ecotechnics leadership position, directed the development of the project, establishing that its scientific and cultural importance called for an iconic building.

In John Allen's chronicle of the design's development, he describes the team's pilgrimages to many of the world's architectural wonders and to magical ancient cities. Ur, Hagia Sophia, Babylon, Teotihuacan as well as the Kennedy Space Center and the Puerto Rican Radio Astronomy Telescope Center would be distilled into the design and image for the Biosphere II. The 'natural' structural system for column free and greenhouse spaces, given the Fuller / Synergist connection, would be a space frame, but without the pure hemi-spherical geometry. The resulting cluster of forms would evoke step pyramids, roman ruins, and a Jeffersonian manor.

This citation of ancient ruins and desire for an iconic presence brings forth just one of the utopian undercurrents of this project. In Miriam Eliav-Feldon's book, *Realistic Utopias*, she identifies "Glorification of a Primitive Golden Age" as one of the eight groupings of "realistic" literary utopias.[12] To refer to a more specifically architectural definition, Miles Lewis identifies two of the categories of utopian projects as the "nostalgic impulse", which sets utopia in the [frequently Gothic] innocent and untainted past, and the "rustic impulse", which often is the agrarian dream of urban intellectuals. These models are seen in contrast to, for instance, the "geometric" or "technological impulse".[13] The myth of the primitive hut would be the architectural counterpart to the literature's primitive Golden Age, be that of spiritual innocence or a simpler, agrarian life.
The Biosphere's design, as *bricollage* from the world encyclopedia of architecture, is sadly a post-modern nightmare come true; the clarity of

Bucky's geodesic intelligence twisted into an iconographically driven assemblage. However, look not to the designer [Engineer/Fabricator] of the space frame, Peter Pearce, as the culprit; he was too deeply familiar with Konrad Wachsmann, D'Arcy Wentworth Thompson, and Fuller's Synergetics to go this route, as he had edited and illustrated an early edition of Fuller's tome. More likely the Director's goal of creating an iconographic building, through citation, steered the project in this direction. This, combined with a sloping site, contributed to the formal contortions and the visually persistent and dense space frame.[14]

BUCKY VERSUS THE BIOSPHERE

If we compare the application of a space frame in the Biosphere to that at the Climatron, program constraints will further explain the different morphologies. The Climatron contained a rain forest in a single space. The Biosphere's program required a diversity of biomes, similar to that in *Silent Running*. However, in the Biosphere, the four programmatically and climatically distinct areas would be aggregated as a single large space with gradual transitions under one complex enclosure. The make-up of the enclosed ecosystems would be less a Noah's ark model or sampling of the entire globe (Biosphere 1), and more of a complex "island ecosystem in that the residents could not leave, and new populations or individuals could not migrate in to rejuvenate or replace resident [plant or animal] populations."[15] The larger place would be sealed, but internally connected. These internal boundaries and transition zones between biomes would be resolved through sectional or volumetric differentiation.

Looking at the larger picture, if this ecological experiment were to test the ability of the inhabitants to survive in a CLOSED loop, and to, as best possible, simulate sealed space life, the architectural solution would need to be the most tightly sealed habitable space ever constructed. A combination of positive air pressure (with the assistance of two "lungs"), a stainless steel lined foundation and over 60 miles of silicon caulking would create a tighter environment than even the space shuttle.[16]

The story of the beings, flora, fauna, and atmosphere inside that three-acre pressure cooker for two years is an interesting tale, but first the enclosure to this pressure cooker. What the Biosphere design team already knew from Fuller's Climatron and '67 Montreal Dome projects was that plastic (acrylic) alone was not a viable enclosure material. Those skins had yellowed and become brittle with time. At the Climatron, a combination of deformations to the aluminum frame and deterioration of the acrylic caused leaking and condensation to occur. This lead to the plastic being removed, the original structure left intact, and a new, aluminum space frame, with larger cross-sections, was

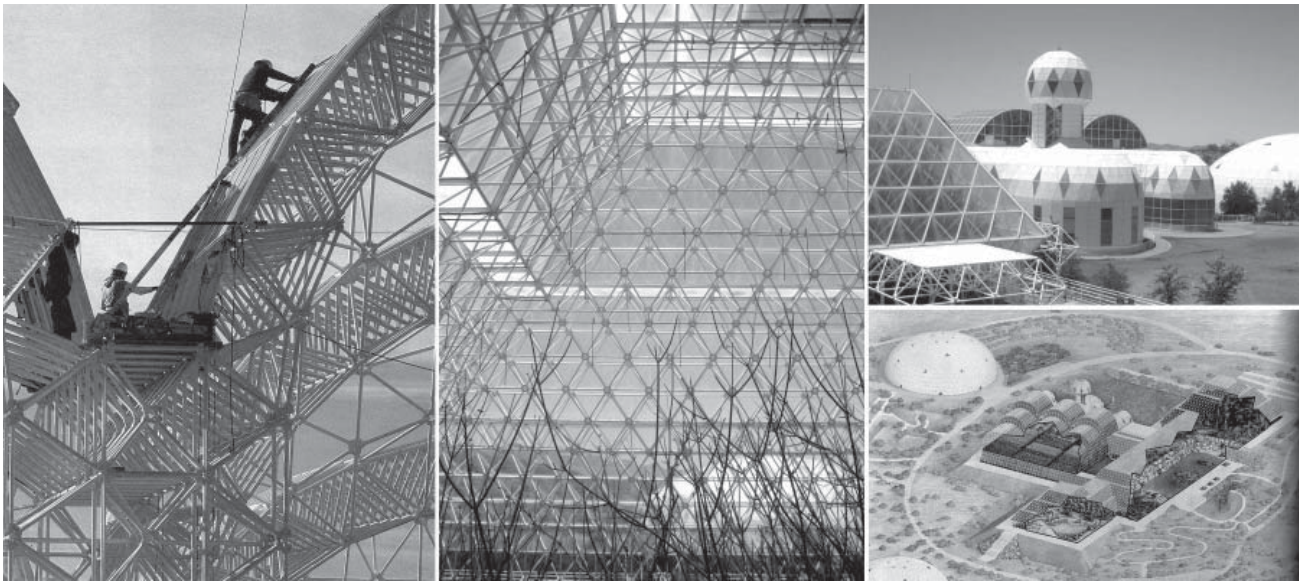

Fig. 4

erected inside to support what would be a four-times heavier glass enclosure. As a worse acrylic example still, a fire during the Montreal dome's renovation produced burning molten drops. The steel rods of this dome survived and today it remains un-skinned with smaller independently enclosed structures tucked inside the skeleton. The institute that inhabits these structures is, ironically, the Canadian Biosphère, a center for eco-action focused on the study of water.[17]

Glass, tempered or not, would not pass the safety requirements nor maintain the seal; one broken pane and the experiment would have been killed. Ultimately a glass/plastic laminated sandwich would be the dominant enclosure material, the weight of which contributing additional heaviness to the contorted space-frame enclosure.

The glass/plastic combination held up and the seal worked. Almost too well. Not all species survived – bees did not do well given the reduced ultraviolet light allowed to pass through the laminated layers; the few all-glass planes were the site of many a bee suicidal attempt to catch rays. As for the human inhabitants, they did not have the privilege of packages of astronaut food as either primary or secondary source of nourishment as in *Silent Running*. The "island ecosystem" model would mandate that the plant-animal-moisture-atmosphere-food waste networks all function in a completely closed, balanced loop. Melons and the other crops they could grow would be their only sustenance. With unanticipated cloudiness due to El Niño and an imbalance of oxygen and CO2, the crop yields were increasingly meager, meaning slimmer portions for the hard-working Biospherians. Hunger plus profound differences of opinion as to how this growing atmospheric imbalance should be folded into the two year experiment, and imagine what transpired! Fortunately there were no off-ings on the mission, as on the fictional Valley Forge, but before the end of the two years the group was divided into two factions of four, never to speak again.

EDEN ACHIEVED

Fast forward again to the turn of the millennium, to St Austell, in Cornwall England. The architect of this last biosphere of sorts, Nicolas Grimshaw, recalls being familiar with the writings of and impressed by Buckminster Fuller, who came to speak in London while he was a student at the Architectural Association. Cedric Price and Peter Cook were his tutors; Archigram's work was in the ether and, by association, one has to assume that any curious student would have discovered the Metabolists who were building what the local Archigram guys were only dreaming of. He was already quite sensitized to the issues of growth and adaptation, energy and resources.

In 1995, Grimshaw was approached by Tim Smit, a former rock and roll manager and proprietor of England's most-visited private garden estate, "the Lost Gardens of Heligan". He dreamt to create the largest plant enclosure in the world dedicated to creating awareness of our human dependence on plant life for our survival and well-being. Smit's agenda was part scientific, part entertainment, part education, and part economic and industrial regeneration. Like the Biosphere II, this needed to be a "Landmark", an iconic structure.

Given Grimshaw's interests from the time of his diploma project to his success with the then-recent Waterloo International Terminal, Nicolas Grimshaw and Partners (NGP) was a logical match for the attitude and ambition of Smit's dream. The primary structure which generally comes to mind when imagining the Eden Project is the second phase building which organizes "the 'biomes', a sequence of great transparent domes that encapsulate vast humid tropic and warm temperate regions,…" [18]

At the project's outset, the structure was more similar in nature, geometry and tectonic logic to the Waterloo terminal – telescopically variable arches, allowing accommodation to the changing section and plan configuration of that site. However, the enormity of the former clay pit and the sectional differential ultimately made this solution unworkable for the Eden project.[19]

To achieve the great span, in the lightest and most economic manner possible, NGP turned to the geometric and structural model of geodesic domes; the interlocking nature of such a structure would accommodate the scale and the extreme irregularities of the site, which were shifting continuously through out the project's development. Undeniably, the resultant form nods and winks at one of Grimshaw's heroes, R. Buckminster Fuller.

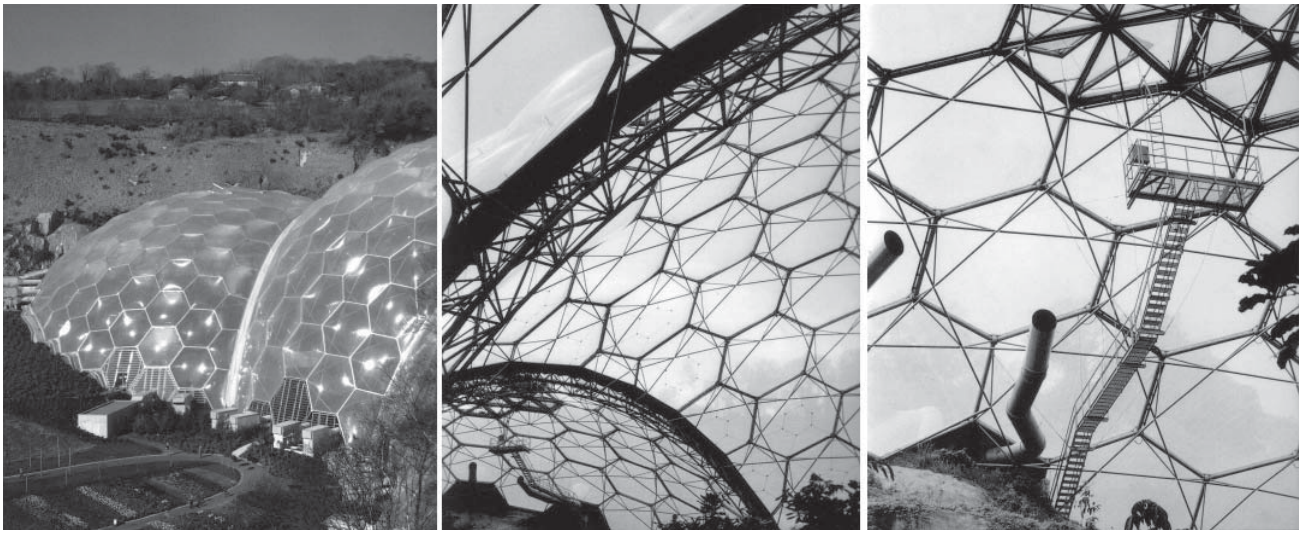

Fig. 5.

Even beyond the reference to the Climatron and the Expo '67 dome, Hugh Pearman, who has written extensively on NGP's work, states that, "there is indeed a not-so-subliminal filmic reference to *Silent Running*, where the last remnants of earth's forests are to be found orbiting…"[20] NGP's Andrew Whalley, who was one of the project's principal designers, acknowledges being a "Sci-Fi Buff" and inspired by the film.

In discussing the development of the project's design, partner Vincent Chang shared that "we [at NGP] naturally gravitate towards structural form,… which is iconic form… However we are not purists… Pure geometry is more iconic (but) not as performative." Chang continued to explain that given the site section, and desire to maintain the heat sink benefits from this, pure geometry was not appropriate. Instead their design solution would "employ geodesic principles in service of more complex programmatic requirements, of efficiency", while maintaining "iconic and didactic legibility". The geometric integrity and legibility would help visitors form a "mental picture" conveying an understanding of the design as "enclosing nature with the structure of nature."[21] *Structure citing nature's logic*, not, as in the Biosphere II design, *architecture citing architecture*.
The project ethos shares much in common with Biosphere II, but from there they diverge. Programmatically, fewer climactic regions were to be enclosed - two biomes separated by an intermediating entry building. Eden would strictly focus on the appreciation of growing plants on earth and not have any outer-space agenda. Instead of grouping several biomes under a single volume, at Eden several volumes enclose a single biome. Instead of a sealed building, the Eden biomes' interior temperature and humidity would be regulated through passive and mechanical exchange with the exterior environment.

The Eden skin, as well, would not be the tight, sealed membrane of the Biosphere. Both however would employ positive interior air pressure as part of the enclosure strategy. Prior to the use of ETFE on the Eden Project, NGP had experimented with the material in a smaller interior application[22]. The material, in fact, had been in existence since 1970, primarily as insulation for cables.[23] ETFE is today's wonder material – featherweight, allowing higher light passage and greater insulation than glass and without the fire/smoke and off-gassing hazards of plastic enclosures of the past. Eden's environment is contained below inflated ETFE pillows of up to nine meters.

Strangely, if we go back to 1970 Osaka Expo, some ultra-thin sheet, possibly a primitive version of ETFE, was the material used in Tange's Space Frame roof over the Festival Plaza. A description in *Japan Architect* from the time reads as follows: "double membrane air cushions made up of multilayers of transparent polyester film… (creating a roof) transparent enough to permit visibility of the sky and the clouds."[24] This early inflated cush-

ion system created an umbrella over, but not an enclosure of, a grand space. Although obviously light-weight, the structure that supported these cushions was of a mega-monumental scale – the antithesis of the Eden Project's expression or the Bucky domes that preceded the Osaka Expo. Advances in material technologies have finally caught up with Fuller's structural vision. At last, there is an enclosure material with a lightness proportional to geodesic structural possibilities.

CONCLUSIONS

Why then did these inflatable film materials not catch on? Returning to *Silent Running's* representation of space-life, in which bio-habitats interminably float in orbit, it is curious that the lure of inflatable architecture, equally present at the Osaka Expo, was completely overlooked in favor of the spatial language of space-frames, geodesics and "metabolic" structures. Working with today's technologies, *Silent Running* could be re-made as science fact / near future. The lightness of geodesic structures, working in tandem with inflated film enclosures, would make the constructing of the *Silent Running* biomes quite believable – certainly more-so than attempting to construct the hulking Biosphere II in space.

But beyond the technical ability to create light-weight and deployable greenhouse enclosures, what would today's motive be? Global climactic swings may lead to many more species' extinction long before we reach the level of toxicity or infertility implied in the film. Current searches for water and life on Mars are likely to lead to longer manned space missions, rendering the Biosphere II agenda of space-life/space-travel and, by association, *Silent Running's* orbiting biomes, a present day / near future reality. For some, more urgent is the need to create new means of feeding and fueling the earth's growing population through space-agriculture. With that in mind, several prototypes for small lunar greenhouses are being developed by University of Arizona and other research institutions for NASA and use in other extreme "climates"[25]. These employ both inflatable enclosure technologies and the clip-on, kit of parts structural systems now inseparable from the "metabolic" architectural vocabulary of space station design.

I would wish that the soon-likely bio-habitats in orbit not become our only surviving "natural" environments, and that these experiments will, like the Eden Project, only render more apparent the preciousness of the earth's environment and the urgency to take visionary actions towards the care of what remains.

ENDNOTES

1. As seen on a wall plaque in the film, adjacent to Lowell's bed in his quarters.

2. *Silent Running by Director Douglas Trumbull.*

3. Mark Dowman has put together a site with a wealth of information about the props, including plans and digital re-constructions, and other general trivia about the film. Much of his content was gleaned from the two documentaries, *The Making of Silent Running* by Chuck Barbee and *Silent Running by Director Douglas Trumbull*, that appear on the 2002 re-release of the Silent Running DVD. www.lunadude.com/pet_proj/valley_forge

4. In the *Feature Commentary with Director Douglas Trumbull and Cast Member Bruce Dern* [2001 DVD] Trumbull and Dern discuss how Dow Chemical had a "pretty bad reputation" because Dow was behind the production of agent-orange used in Vietnam. They suggested to Dow that getting involved in this film might be a "good idea". It appears that, in exchange for their material donations, the Dow, American Airlines, and other sponsors' logos were permitted all over the set. They can be found on the space ship's hull, the earth containers, the space suits….

5. *Silent Running by Director Douglas Trumbull*. Trumbull describes the technique: (front projection is)… "projecting photographs up onto a screen behind the actors to make them seem like they're in a dome when they're really not. We shot it in the airplane hanger in Van Nuys. And did it for very little money; rented plants from a local nursery, scaffolding, a 300 dollar inflatable children's pool…"

6. The **Climatron®** geodesic dome and rainforest conservatory was dedicated in October 1960... The structure … was the first application of geodesic engineering for a greenhouse. The dome is 70 feet high and 175 feet in diameter, permitting tall palm trees to tower majestically above the tropical vista of streams, waterfalls and 1,200 different species of exotic trees and plants. Temperature ranges from 64 to 74 degrees and average humidity is 85 percent. http://www.slfp.com/Shaws081005.html It won the 1961 Reynolds Award for architectural excellence in aluminum. In 1976 it was named one of the 100 most significant architectural achievements in United States history. http://www.mobot.org/hort/gardens/CLhistarchit.shtml

7. www.lunadude.com/pet_proj/valley_forge

8. Editorial. "Space Frame Links Past with Future" *Design Journal*, 1970. http://vads.ahds.ac.uk/diad/article.php?title=259&year=1970&article=d.259.24 "… Kiyonori Kikutake's Expo Tower soars 120m into the air. A vertical space frame held inside three column clusters,

this is a near relative of Peter Cook's exhibition tower project for Montreal. A cluster of viewing capsules, bunched half way up the tower suggests possibilities for extensions and disposability in the accepted Metabolist Archigram manner. But Kikutake's pods have an architectural significance for the clip-on theorists which far outweighs their functional value as viewing stations…"

9. Kikutake's tower heavily borrowed from Peter Cook's unrealized proposal for the Montreal Expo's Entertainment Tower of 1963. Blake, Peter. "Expo 70: Images of the Future," *Architectural Forum*, April, 1970. pp 39.

10. From the "Introduction" by Charles Jenks to Kisho Kurokawa's *Metabolism in Architecture*. Westview Press : Boulder CO. 1977. pp 8.

11. *Silent Running by Director Douglas Trumbull.*

12. The eight types listed are [1] good government, [2] idealization of existing societies, [3] design of ideal cities, [4] glorification of a primitive Golden Age, [5] secret societies [real or imaginary], 6 world empires and plans for universal eternal peace, [7] theocratic millennial kingdoms, and [8] utopias proper. Eliav-Feldon, Miriam. *Realistic Utopia: The Ideal Imaginary Societies of the Renaissance, 1516-1630.* Clarendon Press: Oxford. 1982. pp 3-4.

13. Lewis, Miles. "Architectural Utopias", *Utopias*. pp 117-27

14. Allen, John. *Biosphere 2: The Human Experiment.* Space Biospheres Venture / Penguin. pp 62-3.

15. Ibid. pp 35.

16. They set the maximum allowable leak rate to 10% per year, or 0.027% per day. Biospherian Jane Poynter points out that the "Space shuttle leaks at a rate of approximately 0.05 percent per day". Poynter, Jane. *The Human Experiment: Two Years and Twenty Minute Inside Biosphere 2*. Thunder's Mouth Press : NY, 2006. pp 70-71

17. Access to the US Pavilion was banned from the time of the fire in 1976 until 1990, when the Environment Canada and the City of Montreal developed a plan to convert the pavilion into the "Biosphère". http://biosphere.ec.gc.ca/History-WS7DD2D209-1_En.htm

18. http://www.grimshaw-architects.com/

19. "Our first proposals built upon our work at Waterloo with a series of diminishing primary steel trusses connected to each other with a secondary system, supporting a ridge and furrow glazing system that would have been familiar to Paxton. "The inevitable protracted funding process (Millennium Commission Project) gave us time to thoroughly evaluate our proposals. There were the logistical problems of transporting large steel trusses to and around Cornwall. The quarry's profile also continued to change as the last of the clay was extracted, effectively meaning that our ground terrain was constantly changing as we tried to complete our proposal." From Vincent Chang's Notes for A lecture on ETFE. Courtesy of NGP/VC.

20. Pearman, Hugh, "This Other Eden." The full-length text of the piece was published in the *Sunday Times Magazine*, 25 Feb 2001. http://www.hughpearman.com/articles2/eden.html

21. Author's interview with NGP Partner Vincent Chang and Senior Arch. Robert Garneau on Aug 6, 2007.

22. the Orange Call Center in Darlington, 1998

23. Hugh Pearman states that it has been in existence since the 60's. On a pseudo Dupont site it states that "The Teflon® trademark was coined by DuPont and registered in 1945; the first products were sold commercially under the trademark beginning in 1946. Applications and product innovations snowballed quickly. Today, the family of Teflon® fluoropolymers from DuPont consists of: PTFE, the original resin; FEP, introduced in 1960; Tefzel® ETFE in 1970; and PFA, in 1972. http://www.mindfully.org/Plastic/Teflon/Teflon-HistoryDuPont.htm

24. Kamiya, Koji. "The Space Frame," *Japan Architect*, May/June 1970. pp 51–55.

25. Sorenson, Dan. "Greenhouses for the Moon and Mars". *Arizona Daily Star*. Published 01.07.2007. www.azstarnet.com.

FIGURES

Fig 1. Silent Running Model. Left: Detail shot of domes connecting to truss; Image courtesy of American Cinematographer. Right: long view of truss with Biome-dome. © Universal Pictures, 1972. both at www.lunadude.com/pet_proj/valley_forge.

Fig 2. "A construction worker assembles a portion of the Climatron at the Missouri Botanical Garden. Synergetics, Inc., owned and operated by R. Buckminster Fuller and James Fitzgibbon, was the engineering firm for this well-known example of the geodesic dome. Halftone on promotional printed card by Synergetics, Inc., 1958. James W. Fitzgibbon Papers, Missouri Historical Society Archives. http://www.mohistory.org/content/Fitzgibbon/scope.aspx

Fig 3. Osaka World Expo 1970, Left: Space Frame [Kenzo Tange] and Right: Expo Tower [Kiyonori Kikutake], from Japan Architect, May/June 1970. pp 69 and 71

Fig 4. Biosphere 2. L: Sealing glazing to Space Frame. Allen, pp 58 [image: C. Allen Morgan]; C + top R: Biosphere in 2007 [image by author]; lower R: Drawing of Human + Wilderness Biomes. Allen, pp 34. [image: Space Biosphere Ventures]

Fig 5. Eden Project. L: image by Sumner, C + R: images by Tessa Traeger. From *The Architecture of Eden*. Eden Project Books, 2003, by Hugh Pearman and Andrew Whalley.