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Lydia Kallipoliti

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Article

CLOSED WORLDS: THE RISE AND FALL OF DIRTY PHYSIOLOGY

Lydia Kallipoliti
Rensselaer Polytechnic Institute, Troy, New York, USA
Email: lydia.ka@gmail.com

This paper examines an unexplored genealogy of closed resource regeneration systems, which migrated from the space program to countercultural architectural groups experimenting with autonomous living. More than a cultural fascination with the space program, closed recirculatory systems illustrate emerging architectural concerns related to habitation. They manifest a new integrated structure where man—his physiology of ingestion and excretion—becomes part of the system he inhabits as a combustion device. In addition, as organisational divisions of closed loop cycles, closed systems are computational systems, namely recursive models that generate complex behaviours. "Closed worlds" disclose a struggle to reconcile the utopian ideal of replicating the earth in its totality, with the visceral and raw material reality of "stuff" generated unexpectedly from feedback loops. The genealogy of closed resource regeneration systems reveals how the exploration of outer space fuelled a radical ecological architectural debate as a scientific and an ontological project.

Keywords: Autonomous living; closed systems; earth view; feedback; recirculation; synthetic naturalism
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In his revisionist account of the history of computing in Cold War America, Paul Edwards conjures a closed world that is "radically divided against itself. Turned inexorably inward, without frontiers or escape, a closed world threatens to annihilate itself, to implode".[1] Edwards' history charts the evolution of computation within the political and cultural landscape of a divided global stage set. In this essay, I too invoke "closed worlds", ones that reveal a parallel history of contained microcosms intended as replications of the earth in its totality. While Edwards recalls the literature of Northrop Frye to argue for "green worlds"—the unbounded natural setting of a forest, a meadow, or a glade—as an opposing force to "closed worlds",[2] the closed worlds presented here absorb and sequester the green setting within their boundaries, reengineering nature in pieces of earth.

By contrast with an open system, which is part of an exterior world and linked to its surroundings, a closed system in this essay implies an architecture of "un-rootedness"; it suggests not only a physical reality secluded in its geographical and spatial borders, but also an existential separation of the individual from the urban fabric and eventually from the social sphere. A closed

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system insulates itself from receiving any environmental input as well as from discharging output. Ultimately, it functions like an improvisatory sealed structure that regenerates new conditions out of what is available within its systemic borders. In a closed system, any modification occurs internally, affecting the organisational structure of the system alone.

The starting point to this story is the view of the whole earth, which had been highly anticipated throughout the 1960s and eventually reached its apogee in the famous Earthrise series taken by Apollo 8 in 1968.[3] These images, portraying mankind entrapped in the finite space of a sphere, may be held accountable for a collective feeling of anxiety in cultural imagination as well as a broad literature projecting plans for our future survival within what Buckminster Fuller famously called our "spaceship earth".[4] This immersive imagery might also be held accountable for a genealogy of closed resource regeneration systems, or smaller highly engineered earth microcosms.

"Closed worlds" speaks of a larger disciplinary transformation in the post-war period and the rise of a new environmental consensus in the form of a synthetic naturalism, where the laws of nature and metabolism are displaced from the domain of wilderness to the laboratory and, eventually, to the realm of cities and buildings. More than a cultural fascination with the space program, closed recirculatory systems illustrate emerging architectural concerns related to human habitation. They manifest a new integrated structure where man—the physiology of his ingestion and excretion—becomes part of the system he inhabits, as a combustion device. As organisational divisions of closed loop cycles, closed systems are computational systems, namely recursive models that generate complex behaviours. Such systems demonstrate an ontological problem of creating an autonomous personal space or a protective environmental enclosure around the human. This spatial paradigm, similar to the bubble space of the astronaut's suit, can be described as an "egosphere", which, according to German philosopher Peter Sloterdijk, alludes to a novel territorial paradigm of the twentieth century, modern individualism.[5]

The body's physiology, and its potential real-time integration in the engineering of recirculatory systems, holds significant implications for the living experiments under investigation in the context of this essay. We tend to think of human waste as a phantom material condition, relayed to the management of urban resources; yet, waste infiltrates the air and water we breathe. It is a matter closely enmeshed with the "dirty" physiology of the body and is thus woven into the ecology of habitation. While ecological systems of the post-war period positioned the inhabitant as an indispensable part of building ecology, currently, this image is dismissed. Environmental concerns promote a conservationist ethic and a list of cautionary daily practices of scarcity.

The space program episodes narrated in this essay attest to the "disobedience of machines" as well as the complexity of integrating the body's dirty physiology into closed building systems. Originating in the space program and later migrating to countercultural groups experimenting with autonomous living, closed living systems reflect our inability to mentally or physically cope with the vastness of the earth as a system, seemingly finite and contained, yet infinite. "Closed worlds" disclose a struggle to reconcile the utopian ideal of replicating the earth in its totality with the visceral and raw material reality of "stuff" generated unexpectedly from feedback loops.

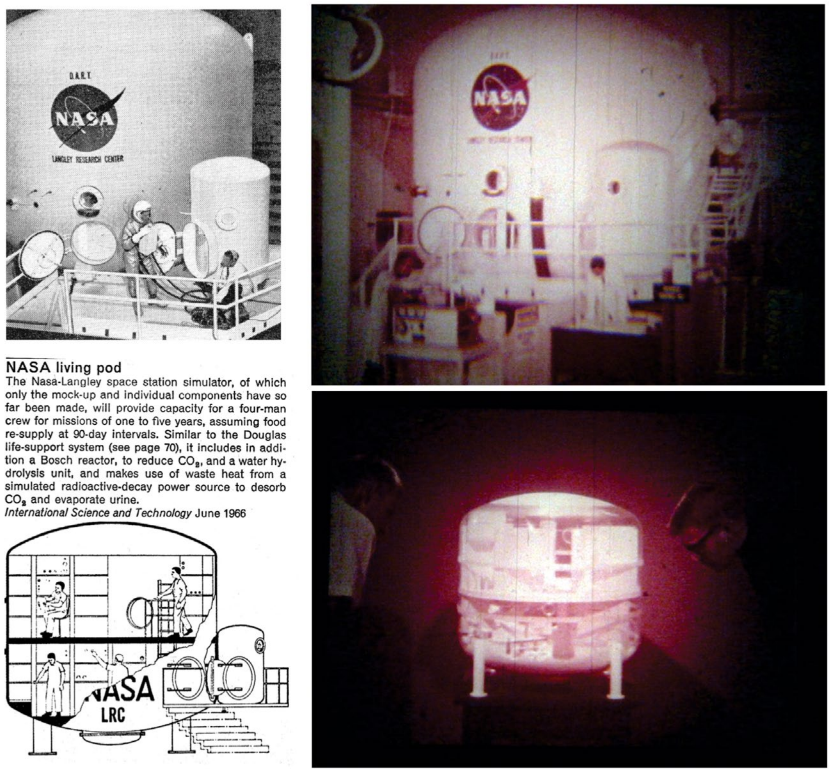

Figure 1. Left: The NASA Langley simulator as it was published in *International Science and Technology* journal in June 1966 (p. 52). Right: Snapshots from NASA's promotional motion picture for television, *The Case for Regeneration* (1960). From the US National Archives, College Park, Maryland.

The genealogy of closed resource regeneration systems reveals how the exploration of outer space fuelled a radical ecological architectural debate as a scientific and an ontological project. Somewhere between the idealisation of the earth as a whole—as a complete and interconnected system—and the messy and fuzzy leftovers of human physiology lies an unexplored history of architecture dissolving into a reconstruction of natural systems.

NASA'S LIVING POD

> *Assuming that an astronaut needs 11 pounds of water and two pounds of oxygen per day, if you seal him into a spaceship how long would this quantity last him?*

The answer, proudly announced by General Dynamics in 1960, was "forever, if necessary".[6] Air and water could be regenerated indefinitely, providing that a total man-machine system is properly organised.[7] To carry man into outer space, we must invent the total man-machine

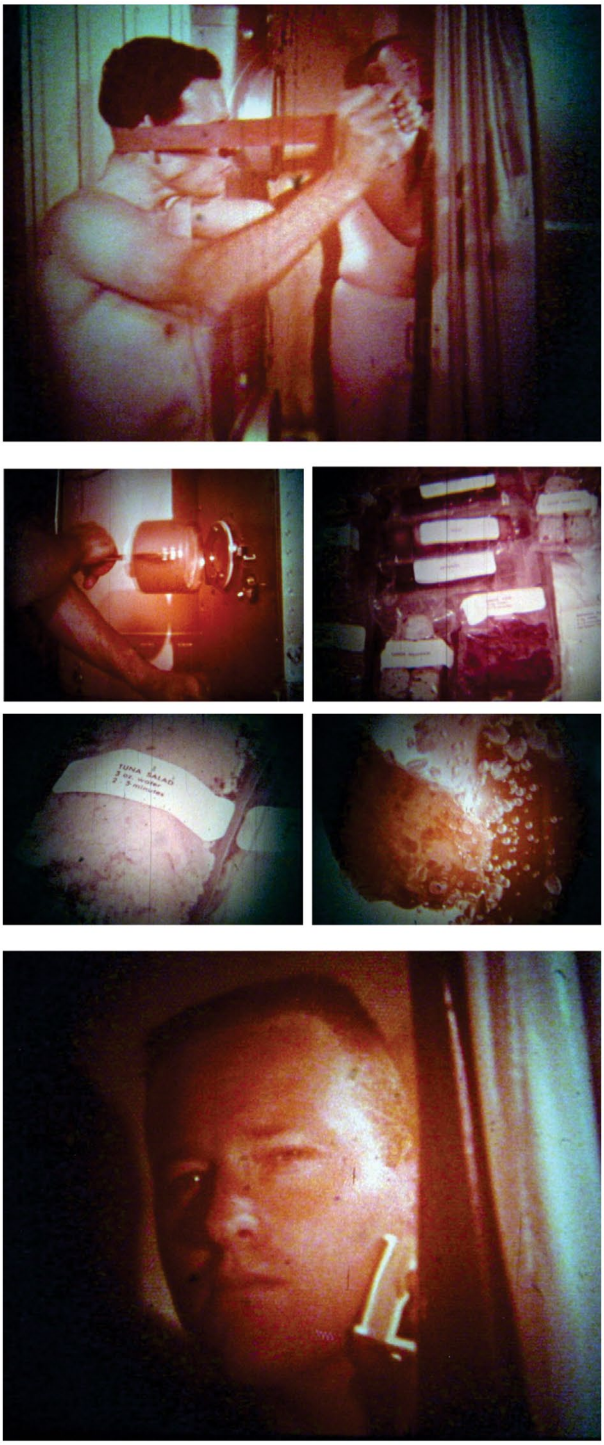

Figure 2. Snapshots from NASA's promotional motion picture for television, *The Case for Regeneration* (1960), illustrating daily practices of personal hygiene and nutrition. From the US National Archives, College Park, Maryland.

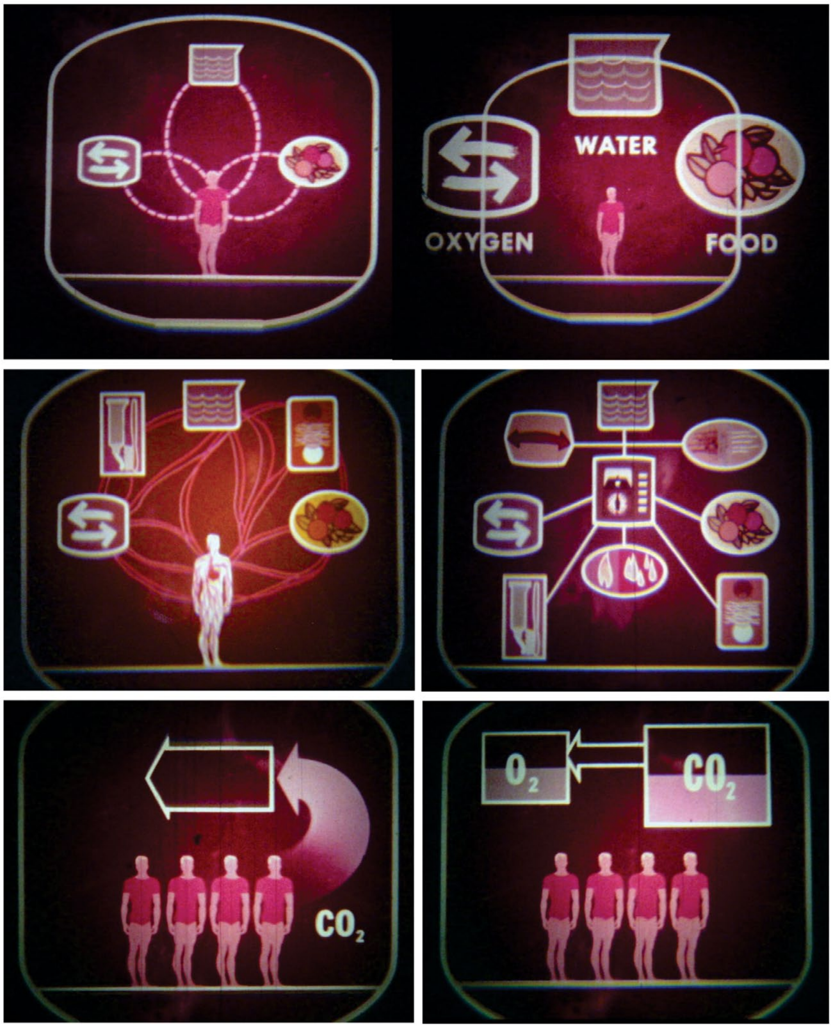

Figure 3. Snapshots from NASA's promotional motion picture for television, *The Case for Regeneration* (1960), illustrating diagrams for regenerating man's output into input and closing the loop of man's physiological daily needs. From the US National Archives, College Park, Maryland.

system: "a man—the living breathing organism—and a machine that functions like an organism, inseparably tied together".[8]

Such was the premise of General Dynamics' project report to the *International Science and Technology* journal in 1966. The corporation's Convair Division in San Diego collaborated in the early 1960s with the NASA Langley Space Station in Hampton, Virginia, in order to manufacture an experimental regenerative life-support facility completely sequestered from the exterior world. The prototype, called the NASA Living Pod, was a sealable, spherical steel hull

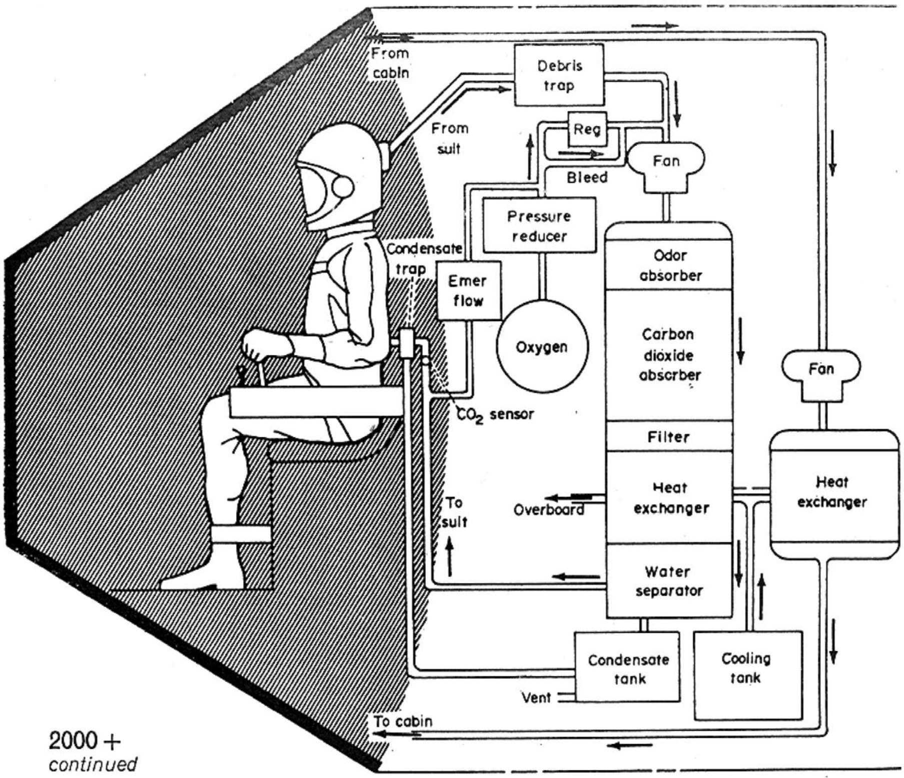

Figure 4. NASA's diagram of an environmental control management for a closed space cabin, as it was published in *Clip-Kit* edited by Peter Murray and Geoffrey Smythen in 1966 and consequently published in Robin Middleton's article "Living" in *Architectural Design* (February 1967, p. 36).

designed to take care of the basic physiological requirements of four men for a full year, with minimal re-supply once every three months (Figure 1).[9]

Prior to this venture, the Douglas Aircraft Company's Missile and Space Systems Division ran living experiments on sealing away crews of men for shorter periods of time. NASA Langley's living pod was superior to its precursor in terms of technological equipment.[10] What was strikingly different is that NASA documented in real time the residency of the four man crew in a promotional motion picture for television entitled *The Case for Regeneration.*[11] Directed by Robert B. Montague and produced by the General Dynamics Convair Division with the cooperation of General Electric Co., the Whirlpool Corporation, and other engineering manufacturers,[12] this motion picture was a prelude to a carefully edited reality show. The film monitored the sealed men shaving, disposing their waste in sealable plastic bags, unpacking and consuming vacuum sealed food, and executing daily hygiene functions with equipment explicitly designed for space travel. This record of daily practice was publicised as the dawn of a new space age off the earth, in celebration of mankind's boundless territorial expansion, outwards to the unexplored margins

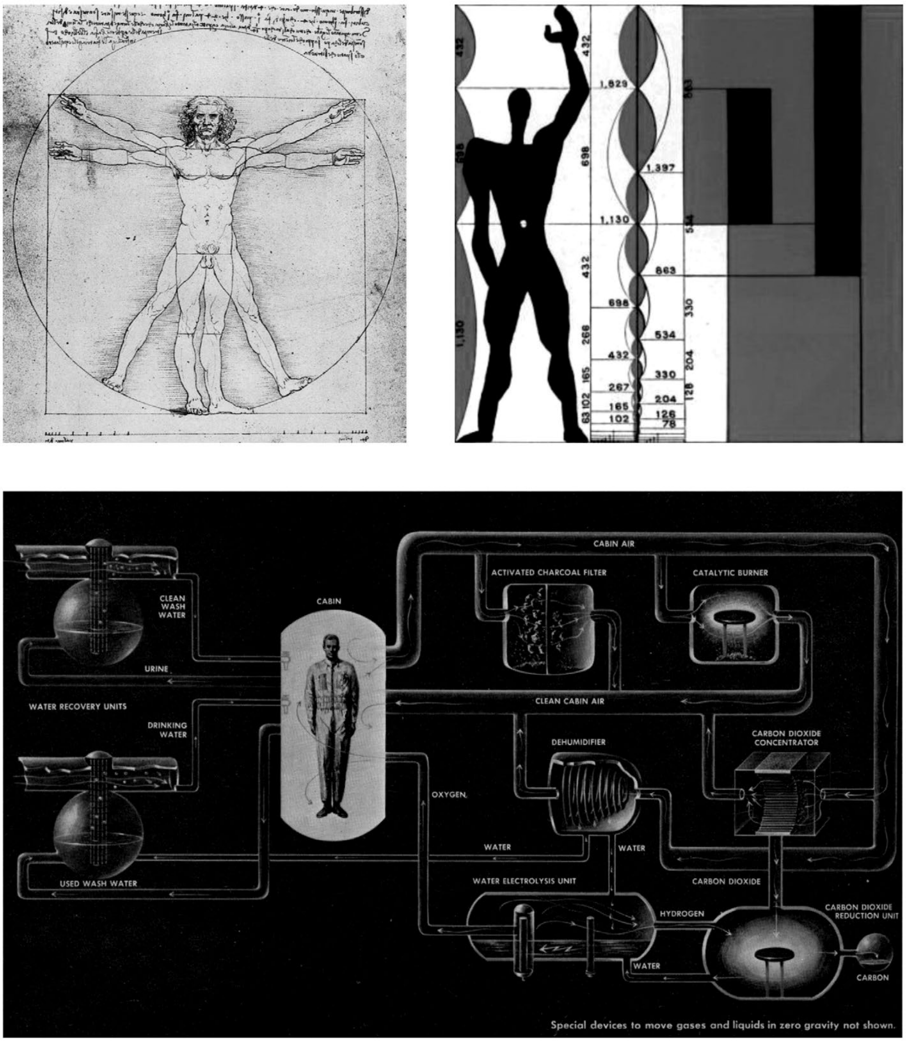

Figure 5. General Dynamics diagram for a life-support system (bottom), compared to Leonardo Da Vinci's Vitruvian Man (top left) and Le Corbusier's Modulor (top right) (*International Science and Technology*, June 1966, pp. 52–53).

of the cosmos. "It was inevitable that man, the insatiable explorer, would build a stairway to the stars, where the conditions are unfriendly to his biological system",[13] the NASA movie tells us. The key, however, to the colonisation of this new frontier no longer lay in the invention of rockets and armed weapons, but in the management of human physiology. For man to transport himself into outer space, he would need to carry along an artificial environmental earth bubble (Figure 2).

The Case for Regeneration was an early televised project of NASA's pioneering "brand journalism", part of an aggressive strategy of the 1960s space agency, which, as David Meerman Scott and Richard Jurek argue, ensued later on in the selling of the Apollo program.[14] In parallel with the living experiment as a stage set, medical practitioners, chemical engineers, physiologists, food technologists, microbiologists, analysts, and architects were brought together to study men in the living pod. These men were rigorously trained to use the facilities of the living simulator and test their actions in the hermetically sealed environment. Everyday routine habits, including how to shave, how to clean their bodies, how to urinate, eat, and even sit, were vital to the duration of their stay in the pod. If they were to venture into space, it would be necessary to convert all of their human waste to oxygen, water, and, hopefully, food. Human waste products, even urine, would be processed to reclaim water using techniques of electrodialysis, closed-cycle air evaporation, and vacuum compression distillation.[15]

Howard W. Mattson, a food technologist and associate editor for *International Science and Technology*, described the bonding of man and machine as inevitable. In order to maintain life within the borders of an artificial enclosure, the space probe needed to be a recirculatory breathing machine, a sample natural ecosystem, which was carefully constructed to match, one by one, all the characteristics of such systems. Mattson was mainly speaking of space exploration; his scenario, though, was quickly adopted by John McHale, who projected Mattson's agenda to a ground-based sealable miniature earth probe, as a futuristic habitation model. In the "Outer Space" issue of *Architectural Design* magazine, edited by McHale in 1967, Mattson's life support rules for "Keeping Astronauts Alive" are transferred unprocessed as readings for architects, in the face of a discipline's stagnation to provide viable habitation solutions for an endangered planet under environmental attack. McHale wrote: "To transport and maintain the human organism off the earth and outside its sustaining envelopes, the space capsule needed to be a microcosm of the terrestrial world…. Recirculatory power systems, breathing units, protective shields, energy collectors and converters, namely an internal closed system ecology was designed to converge all waste streams to useful ones".[16]

Crucial to the description of "man-machine" systems were human feedback loop diagrams, illustrating the body as a closed ecology (Figure 5). In these diagrams, ingestion and excretion cycles were strategically edited through the use of external apparatuses, which were assigned the mission to effectively recycle all material flows. The General Dynamics diagram for a life support system visually rendered an obsession with monitoring, capturing, and recycling human subsystems. As a result, a new biotechnological image of man emerged, one where human agency was delegated in terms of input and output.[17] At the same time, the diagram illustrated man bound to his environment; only with the service of digesters, converters, dryers, and dehumidifiers could all cycles of ingestion and excretion be closed and redirected back into the body.

The figure of the system connected man can neither figuratively nor literally be disconnected from the larger history of cybernetics and the neologism of the "cyborg", which Nicholas de Monchaux points out was originally used by psychopharmacologist Nathan Kline and mathematician Manfred Clynes for man–machine hybrids.[18] While Kline and Clynes proposed to chemically alter man's physiology and to adapt subjects for space travel, rather than reconstructing the space cabin as an earth replica vehicle,[19] their ideas sit comfortably alongside the General Dynamics diagram in a lineage of similar diagrams illustrating the bonding of man and machine in a closed circuit. What is different about this particular image is its reproduction in several architectural publications, like *Architectural Design*, *Bau*, *Clip-Kit*, and *Adhocism*. Outsourced from NASA, such diagrams portrayed a new vision of man and the space in which he resided, as if tied to its walls and parts by an umbilical cord. Reporting on NASA's Living Pod in 1966, *Clip-Kit* called the architect's attention to the rising field of biotechnology, which necessitated a systematic decipherment of man's physiological functions. The magazine's editors argued that the process of integrating man into complex flight missions—and, consequently, the study of life support systems and protective enclosures in association with human factors—was not just a matter of technology, but also a matter of culture. The expansion of the relationship between man and environment was bringing to the surface a new spatial schema of the body conflated in the space it inhabits.[20] *Architectural Design*'s technical editor, Robin Middleton, reported in McHale's "Outer Space" issue that the "oxygen-regenerative space capsule might become our image of the ideal living environment",[21] one with constant flow of clean air, free from carbon dioxide and moisture (Figure 4).

Architectural journals were eager at the time to publish diagrams showing "a new image of man", an image that would portray man as a feedback system. Rather than a static encircled figure or an idealised geometry in mathematical proportions, feedback man was in constant fluctuation with the environment. Using the Vitruvian Man as a visual reference to a previous paradigm, NASA's doctors described the new version of man as a "combustion engine in regular exchange with the atmospheric flows of contiguous micro-environments". In a NASA Report from the School of Medicine at the University of Southern California, the doctors wrote that "space-age medicine is researching dynamic man rather than static human subjects: man in health as well as in sickness; asleep and awake; fluctuating and variable; man in motion; man in time".[22]

In many respects, architectural drawings of man are a measure of worlds, an image personifying the architecture of different eras. Thus, Vitruvian Man, inscribed in a circle, speaks of a period of geometrical supremacy (Renaissance humanism), while Le Corbusier's Modulor, measured on an external reference line, reflects an architectonic vision of idealised proportions underwriting modern architecture. The General Dynamics diagram, however, projected the materiality of the human body dissolved in a series of flows and feedback loops compressed into a spacesuit or a pod. The image of man in the enclosed capsule, mapping human ingestion and excretion in circuits of feedback flows, depletes any bodily distinctions between interior and exterior. It reinscribes the human figure in a new elastic circle where the body and the environment have merged (Figure 5).

The various diagrams of "feedback man" represent a wider cultural interest of the 1960s. The mission of inhabiting a boundless new space, out of the earth's safety blanket, actuated an alternative description of the body in space, a visualisation which had profound implications for architecture, crossing different scales of reference. In a sense, the further we went out into the cosmos, the inner we looked into man. Indeed, doctors of the University of Southern California reported

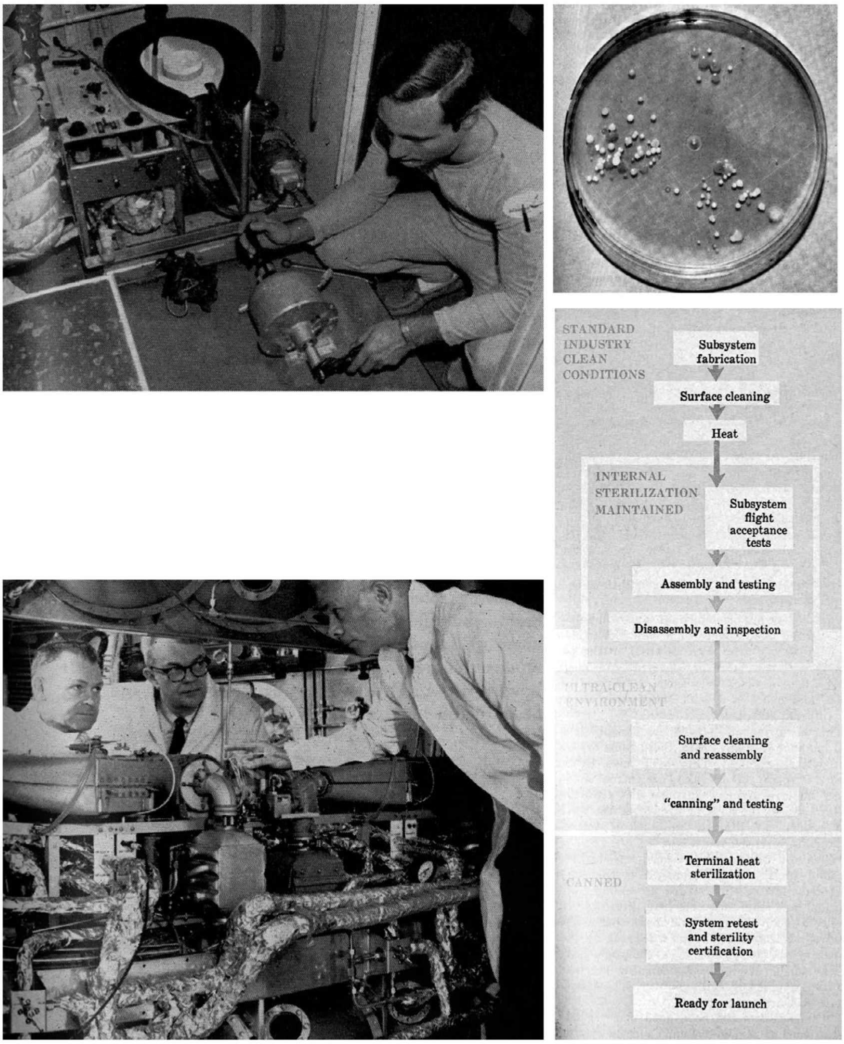

Figure 6. Left: Lawrence B. Hall, "Sterilizing Space Probes", *International Science and Technology* (April 1966), 50–61. Top left: Waste management equipment in the Douglas spacecraft simulator. The simulator, which has run with a crew of four for 62 days, encompasses a regenerative molecular sieve for carbon dioxide concentration, a catalytic toxic burner, a zero-g toilet, and a zero-g cabin condensate recovery system with systems to purify condensate, wash water, and urine, using air evaporation and electrodialysis (p. 61). Bottom left: In the NASA Langley space craft simulator by the Convair Division of General Dynamics, urine and wash water are air evaporated in the two flat boilers as shown in the centre of the photograph (p. 51). The square boxes are heat exchangers; storage tanks are above and below. Waste management functions include several areas of development to provide for the collection and processing of faeces and the collection and transport of urine under zero-g conditions. Both collection functions employ a ducted air stream to impart velocity to the waste materials and to minimise cabin odours. The configuration selected for faecal collection resembles a stool with provisions for collection of the faeces in a semi-permeable bag. Design for zero-g requires protection against contamination of the cabin environment plus considerable emphasis on practical and manageable methods of collecting and transporting used water back to reprocessing. Right: Howard W. Mattson, "Keeping Astronauts Alive", *International Journal of Science and Technology* (June 1966), 28–37. Top right: Air contaminants collected in a sterilised probe in a closed manned living simulator (p. 33). Bottom right: Diagram illustrating the sterilisation process of NASA's manned closed living simulators. (p. 33).

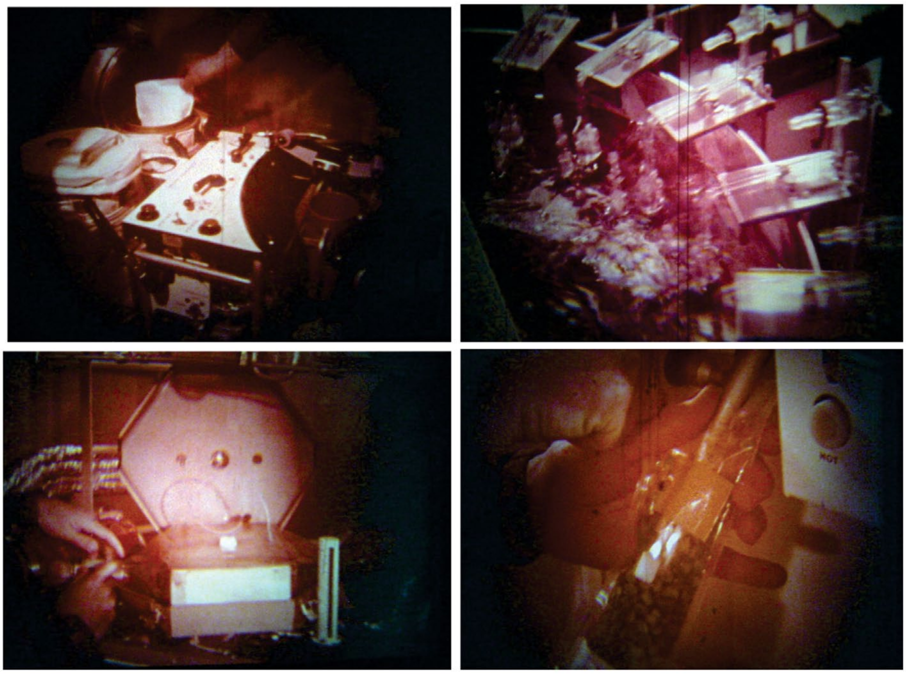

Figure 7. Snapshots from NASA's promotional motion picture for television, *The Case for Regeneration* (1960), illustrating the environmental control and sterilisation systems in NASA Langley's living simulator co-sponsored by the Convair Division of General Dynamics. From the US National Archives, College Park, Maryland.

in NASA's spin-off program, NASA Technology in the Service of Man, "our great twentieth-century space adventure has become far more than a long journey to the planets. It has become a journey into man".[23] Looking inside the body helped render fields of stars, clusters of galaxies, aggregations of planets, and the accretion of cosmic dust into the boundlessness of outer space.

CONTAMINATED EGOSPHERES

The image of man as a heroic explorer who overcomes his physiological boundaries and conquers uninhabitable lands was at the heart of the 1960s, projecting the astronaut as a new universal human subject. "Astronauts are envoys of mankind", stated the Outer Space Treaty of the United Nations in 1966.[24] "If an astronaut lands on another country's soil he must be returned safely, promptly and unconditionally".[25] The astronaut, masked and geared, became a positive figure of unbounded progress, equipped to carry in his spacesuit a piece of the earth's environment. Outer space, the bottom of oceans, Antarctica—regions unfriendly to the physiology of humans—were all part of an envisioned new democratic political reality. Outer space and analogous inhospitable regions were places that defied territorial claim. In this vast, blank space, humanity had a second chance to reinvent itself from scratch.

However, this democratic venture came at a high, almost deadly, cost, recalling a primitive fear that man could be buried in the combustion products of his own body. In case of systemic malfunction, excretion could kill him or contaminate his environmental "egosphere".[26] In this sense, the system could not be anything less than 100 per cent foolproof, with compulsory regeneration its maxim and material loss negligible or non-existent within the closed state. Inhabited space was in the faithful service of closing all loops: a capsule furnished with garbage units embedded in the walls to collect urine and equipped with carbon dioxide collectors, floating human waste divisions—all needed in order to accumulate all waste and facilitate feedback.

In early space capsules, it was the leakage of breathable oxygen that rescued the occupants from contaminants. It removed contaminants in the cabin fairly rapidly and prevented problems of toxic build-up, which arose from the "less-than-perfect" airtight housekeeping in early capsules.[27] In fact, the Mercury capsules leaked as much oxygen as was breathed by the astronauts. However, the success of a closed system could not depend on fortuitous leakage from the space cabin. Explained by Lawrence B. Hall, an interplanetary quarantine officer at NASA, sterilising space probes was an absolute necessity to prevent the possibility that any terrestrial life brought along on the probe interfered with life that already existed on a planet.[28]

In the living pod at Langley, the subjects experienced nausea and headaches, and eventually contaminated the system with their own waste. Shed hair, fingernails, and skin infiltrated the collectors; eventually, the subjects had to be removed from the cabin earlier than expected. In addition to carbon dioxide, contaminants in the closed ecosystem of NASA's Living Pod included minute waste particles like dust, hair, skin debris, tobacco particles, odours and toxic substances from cooking, and other formed organic compounds with unpleasant odours like indole, skatole, amines, volatile oils, phenol, nicotine, spores, viruses, and sacrophytic bacteria that decompose organic matter. The extent of the contamination was not recognised until the NASA Living Pod experiment, primarily because of the high leakage rate in earlier spacecraft. Once the living experiment took place, there were over 400 contaminants identified in the simulator. Those outgassed from the simulator's materials—from paints, coatings, plastics, and insulation materials—were in low concentrations, yielding vapours such as benzene, formaldehyde, and acetone. Contaminants produced by organic processes, however, were especially harmful. Metabolic processes produced methane, carbon monoxide, and ammonia (Figure 6).[29]

After the men were extracted from the closed living pod, scientists involved in the experiment used the term "black box" to describe the chemosynthetic conversion of materials from output to input. What is important to observe in this case is that the malfunction of the system was not the direct result of the malfunction of its subsystems or feedback loops. The subjects did store their waste in the designated compartments after conducting their daily personal hygiene routine, as illustrated in the feedback diagram (Figure 7). Yet, floating waste material, material so finely grained that the recirculatory process could not capture it, escaped and eventually randomly coagulated in disorderly patterns, namely contaminants. These very contaminants were considered "new bodies" produced by the system (the coagulation and sedimentation of free-floating energies), leftover by-products from the transference process central to the metabolic model reduced to sediment and crystallised into new extraneous material bodies.

In the case of the NASA Living Pod, the cybernetic feedback diagram failed to predict the evolution of the pod as a living system that produced new matter. The diagram, with all its multipart recursion loops, could not encompass the partial local material bodies that were formed in a different scale. Eventually, these new bodies destabilised the overall structure of the descriptive system, and unforeseeably pervaded the balanced function of the closed ecosystem.

Captain Robert Freitag, deputy director of the Manned Space Flight Center at NASA, declared in a conference at Princeton University in the late 1970s that much is still unknown in many areas of interaction associated with the development of a closed ecosystem. He proposed that algorithms had to be developed to define the basic supporting relationships between man, animals, plants, and microorganisms in order to define the conditions under which ecological closure might exist. This area could prove to be the single most demanding technology to be developed in the twentieth century.[30] After years of experimentation with ecological closure, biologists at the time came to similar conclusions: despite the rigour of mathematical formulas, contained artificial ecosystems were unpredictable in their evolution.[31] If subtle ruptures occurred in any of the systems' parameters, closed worlds had no "healing mechanism".

Notwithstanding a decade of investment in ecological research, Stewart Brand confessed that self-sufficiency as an idea was a type of hysteria.[32] Since the inception of the *Whole Earth Catalog*, Brand held a long-standing obsession with advanced technologies for outer space as well as toolsets for craftsmen in the framework of the American Southwest communes. Through his publications, it was clear that, despite the ostensible contradictions between high-tech and low-tech devices, the affinity between the closed ecology of the space cabin and ecological design of environmental buildings on earth was so powerful that, in his mind, there could hardly be a distinction between the two systems. In the late 1970s, Brand confessed in his *Co-Evolution Quarterly* the uninspiring results of time-consuming experimentation to reconstruct autonomous artificial ecologies. He wrote: "Self-sufficiency is an idea, which has done more harm than good. On close conceptual examination it is flawed at the root".[33]

Brand's account of a kinship between the closed system and the hysteric body is critical if we reflect on Freud's definition of hysteria as a physiologically internal modification of the nervous system.[34] The failure to specify a physio-pathological formula for hysteria as well as the fact that the condition cannot be diagnosed as a whole, but through a disjointed cluster of symptoms, is in many respects analogous to the "black box" unpredictable material formations in closed, self-sufficient systems. In the NASA Living Pod, contaminants emerged as new material bodies through the system's by-products; they were infinitesimal, free floating human waste material, which could be read as conditions of "excitability" aroused in different sections of the space cabin's nervous system.

This whole process of converting output organic material to useful input was exhorted by enormous scientific anticipation to transform excrement into new life. Closed regenerative systems are one more example of the greatly desired scientific impossibility, with a striking resemblance to the fantasy of perpetual motion machines.[35] Besides the objective of perfecting the closed cycle of the space probe so as to carry man into outer space, this conversion ambition recalled an ancient alchemic desire to "turn shit into gold". It was seen as a metaphor for healing the entirety of the planet by converting all waste into edible foodstuffs and usable goods.

While technically infeasible, the visualisation of closed systems and the imagery of their performance have provided a powerful visual language that has inspired architects ever since. As opposed to the Vitruvian Man and Le Corbusier's Modulor, where man physically occupies space, the cybernetic model illustrates an operational fusion between man and his milieu. Rather than a vocabulary of ergonomy, "feedback man" illustrates dissolution of the materiality of the body into the elements of space, a biotic de-synthesis, echoing, one could argue, a death wish.

SOCIALLY CLOSED SYSTEMS

Despite the contamination problems for closed living simulators evident in NASA's reports, the space race intensified the projection of civilisation away from the earth and the deployment of outer space research as a laboratory for evolutionary experimentation. Following Apollo 11's first lunar landing in July 1969, America's next big project was to manufacture large orbiting space stations where people could live for extended periods of time. Although the orbiting space stations were not scheduled to be completed before 1975,[36] NASA requested three aircraft engineering corporations to bid for a contract to develop advanced space stations in the late 1960s. These companies were the Grumman Aircraft Engineering Corporation in collaboration with Lockheed Space and Missiles Company; the General Dynamics Corporation and TRW, Inc., allied with the McDonnel Douglas Corporation as well as with the International Business Machines Corporation; and the North American Rockwell Corporation, partnering with the General Electric Company.

In order to visualise a comfortable earthly interior within the orbiting station, Grumman hired the New York architectural firm Warner, Burns, Toan & Lunde (WBTL), which, as *New Yorker* journalist Henry S. F. Cooper reported, led to a lot of friction between the two groups when they could not agree on what best defined a closed system. The engineers feared that architects esteemed habitability as an intuitive "black art",[37] and would not take sufficiently into account the optimal location and function of several mechanical components in the space station. In turn, Danforth W. Toan, partner in WBTL, thought that the engineers, despite being diligent in their analyses—"Mission Objectives", "Life-Support Systems", "Electrical Systems"—compartmentalised knowledge in bits and pieces to the detriment of the overall scope of the project, which was to transport and project a new world in the vacuum of space. Toan battled with Grumman's engineers who saw the space station as a collection of functional machines and were oblivious to the effect of the new social and environmental microcosm they were about to build.

Toan suggested changing the colour of light in room modules through a 24-hour cycle to alert dwellers to the passage of time. An adaptable, changing environment was a prerequisite,

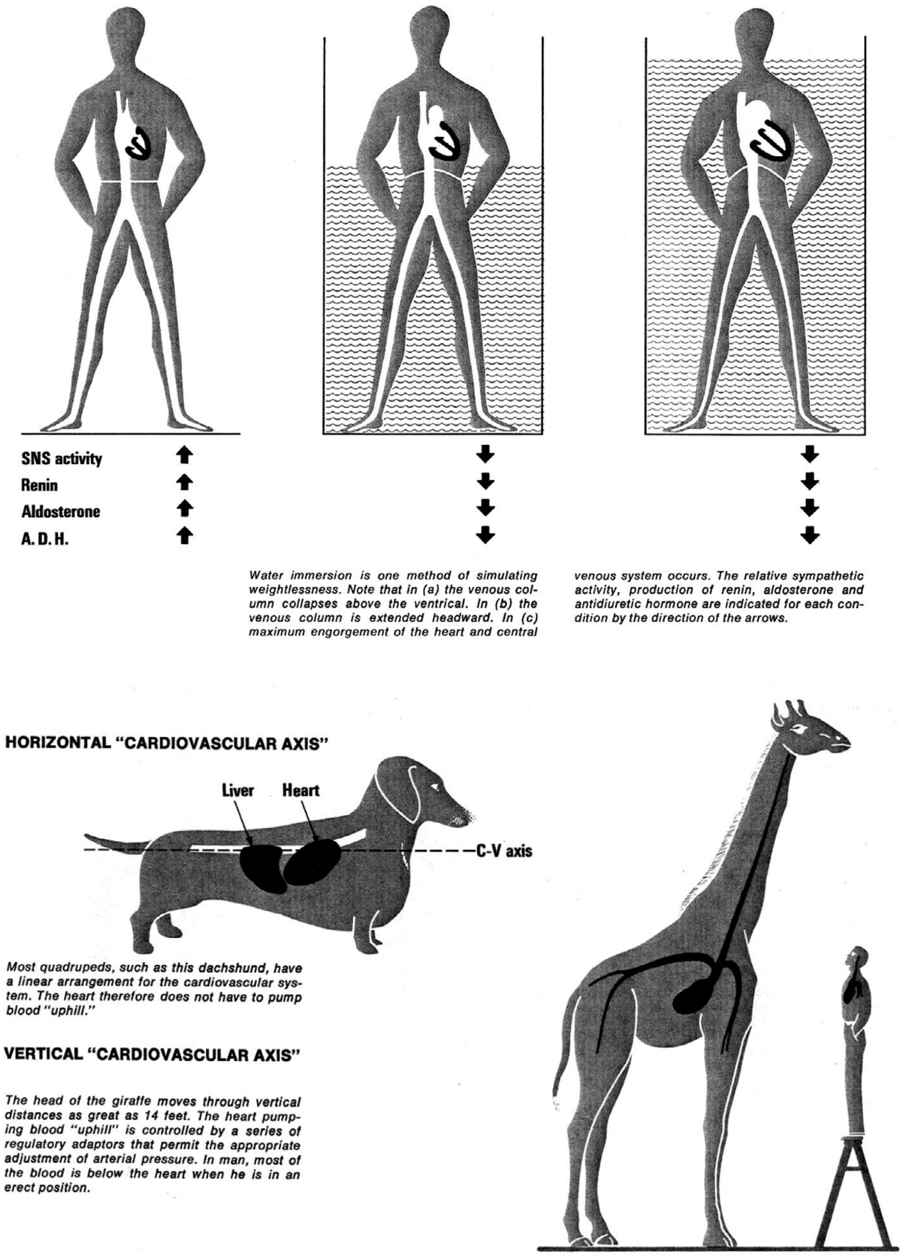

Figure 8. Illustration of cardiovascular and respiration effects in human and animal physiology during extended periods of weightlessness. Documented in NASA's report "Gravity", from the University of Southern California, School of Medicine, Department of Physiology, p. 5. From the archives of the Grumman Corporation in Bethpage, New York.

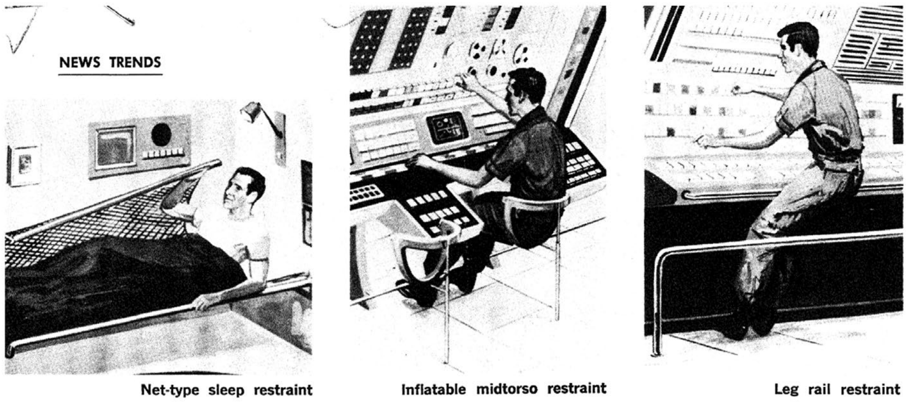

Figure 9. Illustrations of restraint devices for zero gravity conditions devised by Grumman Corporation. The illustrations were published in Grumman's report "Grumman Engineers Solve NASA's Zero-Gravity Environment Problems" in the *Commercial Review* on 11 January 1971 in New York. In the archives of the Grumman Corporation, Bethpage, NY.

according to the architects, who worked closely with psychologists, physiologists, and sociologists in an attempt to reinvent habitation in a three-dimensional contained environment. The psychologists were wary that intense stress would build when groups of two or more people lived together in confinement, exacerbated by the experience of floating in outer space.[38] They also speculated that if the space a group of men were confined in was subdivided into small rooms or over many separate levels, the men allocated to one area would grow suspicious of those living in other areas.[39]

The interdisciplinary group of scientists working on development of orbiting space stations hypothesised that the closed system would be as unproductive in social terms as it proved to be in material terms in the case of the NASA Living Pod. The unanticipated build-up of contaminants in the simulator, which eventually destabilised the anticipated loop function of conversion systems, appeared in a new light to the eyes of the psychologists. They translated the material destabilisation into a metaphor for the rupture of social balance, translating the relationships of people in containment as an analogue to the recirculation of substances in the living pod. After interviewing architect Eric Pick, who studied human stress factors in manned orbital space stations, news feature reporter Vivian Brown wrote that:

> In studying how a group from six to nine people can live together in space for six months or more and survive the experience, the architect decided it will not be easy, for man has not been conditioned to confinement. His restlessness on earth may account for such upheavals as divorce, riots and wars. In such conflicts, he is really rebelling against a hostile environment.[40]

Figure 10. Cover of *The Futurist* magazine in October 1969. The cover featured the interior of a space station by the North American Rockwell Corporation partnering with the General Electric Company.

Toan confessed to Cooper in his interview for the *New Yorker* that "when a field is growing (like architecture was at that time) it rapidly needs to rebuild its language".[41] In addition to the serious issues of confined spaces investigated primarily by psychologists, Toan stressed the significance of life contained in three—equally occupiable—dimensions, a fact which would fundamentally subvert the perception of space. In zero gravity, functional space is the entire volume of a room in cubic metres. Initially, Toan proposed posting pictures of Leonardo da Vinci's Vitruvian Man in the rooms of the space dwellers as a visual reminder of multidimensional occupation in zero gravity conditions. For Toan, the circle represented a better geometrical description for free flow movement in weightless space when contrasted with the horizontal and vertical axis system on gravitational earth.[42]

Although weightlessness may seem irrelevant to the handling of waste, both weightlessness and waste are heavily dependent on the conceptual outline of the circle. The ecological discourse of the 1960s and 1970s was constituted as an artificial circular form of reasoning. To recycle waste was in many respects to adhere to a logic where all living bodies and organic materials should be at the disposition of natural ends and reciprocal uses in flux in the universe. The death of one thing should always be subservient to the constitution of another. Recurring circular restitution promised a new world that would recycle materials perpetually and feed all leftover substances back into cycles of production. As Toan suggested for the habitability of space stations, the geometric outline of the circle proved critical in studies of weightlessness, as it defined the perimeter of a captive world reconstituted anew without gravity.

At first sight, weightlessness raised ergonomic issues in the utilisation of interior space. How can one perform routine daily tasks in zero gravity? As Cadwell C. Johnson, chief of the Center for Spacecraft Design at NASA, questioned in a more entertaining tone, "Can you imagine trying to mix a martini in zero-gravity?"[43] To solve problems of mobility and hygiene in zero gravity, the Grumman Corporation was commissioned by NASA to produce a thorough research report under a space agency contract with the Manned Spacecraft Center in Houston.[44] Grumman recruited a space program team of 28 environmental engineers, psychologists, flight surgeons, physiologists, and microbiologists to come up with conceptual answers for a "clean atmosphere" in weightless space.

The initial issue that was discussed among the group was man's loss of the erect posture and eventually his loss of directional sensation within the closed non-gravitational world of the space station. Parallel to functional limitations, man's negotiation of movement between axes signalled for psychologists a regression of the individual to earlier life stages. As a visual analogy, we may envision floating as a staged process of devolution from the posture of the fully grown erect man to the adolescent, the child, and finally to the newly-born infant whose skeletal structure and bodily tissue are so flaccid that it cannot carry its weight upright. In the course of this regression, the body would subconsciously return to an infantile state and lose its central point of reference. This devolvement of man's erect posture undermined confidence about not only the functioning of man's musculature and skeleton, but also his state of mind. The psychologists' assumptions were reflected in medical assumptions and conclusions by doctors and physiologists, who confirmed severe symptoms in blood circulation from gravitational influences. When the cardiovascular axis of an animal or human is flipped from vertical to horizontal, possible symptoms included mineral loss, increase in secretion of fat mobilising substances, and cardiovascular deteriorations, as well as induced stress and excessive excitation (Figure 8).[45]

Following a series of experiments with animals and men, Grumman's hygiene and mobility study resulted in proposals to tie floating men into restraining bodily fixtures that were described by reporters as versions of spatial "straightjackets".[46] Restraint devices included handholds, handrails, leg-rails, foot restraints, elastic nets for sleeping, inflatable mid-torso restraints, portable bars, and other devices. When water was involved in the operation of personal hygiene equipment, the engineers decided to force air streams in suction water drains to prevent water droplets from floating around aimlessly. All air flow equipment was enclosed in special airtight compartments, like in wash basins, bathroom commodes, and trash disposals (Figure 9).[47]

Life in weightlessness and the freedom of the body appealed to the collective imagination and evoked quite enthusiastic expectations from architectural critics. Alis D. Runge, correspondent in *Progressive Architecture* magazine, asked: "Where is the fun, after all, if the Earth environment is too closely duplicated?"[48] Does the space station's closed world, within its confined non-gravitational perimeter, offer the opportunity to generate new habitation possibilities? However, man's ultimate unrestrained mobility eventually brought forth an architecture of restraint. Familiar settings and space management techniques like dividing a space into horizontal sections and walled rooms were reproduced in the interior design of space stations in an effort to make the new frontier appear less uncanny. Evident in the 12-man space station conceived by North American Rockwell Corporation, the crew quarters are divided over five levels, with men performing earthly routine tasks like working at a desk, exercising, showering, and reading books.[49] North American Rockwell's space station interior was featured on the cover of *The Futurist* magazine in October 1969 as an incentive to assure readers that the colonisation of outer space would be as recognisable to dwellers as the section of a multi-story building on earth (Figure 10).

In the vacuum of space, the risks appeared too high to reinvent habitation. In weightlessness, the repositioning of the skeleton, bodily matter, and, ultimately, of the senses were forecast to induce hyperbolic stimulations in human neural systems, with effects that could not be anticipated. In some cases, hyper-stimulation could lead to the atrophy of normative organic functions. Overall, this whole search to reinvent habitation, to look deep down into the physiology of man, and ultimately to render a material bonding between man and environment were in a very real sense projected to the reinvention of the house. If outer space were to be socialised in earthly terms, the earthly house was to be reconstructed as a closed system in the terms of the boundless vacuum.

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Today's debatable predisposition to provide hermetically sealed air-conditioned buildings, which are soon after dehumidified, leaves open questions as to the leverage of legacies and the ways in which they migrate from military research to cultural beliefs. On these grounds, it is within our present obligations to interrogate conflicting definitions of ecology and the paranoia of sealing as a cultural by-product of nuclear disaster fear and the space program. It is imperative to question the value of closed systems, both as national policies and as an architectural genealogy. The closed system proved impossible as a practice and hysterical as an idea at many levels. It did, nonetheless, raise issues that only very recently have had consequences in contemporary practice through the revival of fascinations with biology, organic matter, and material conversions.

On the one hand, the environmental campaign suggested a new moral and scientific discipline, of a culture with no waste, transferring an ideological framework of politics and ethics to the domestic realm. The idea of waste becoming extinct projected a holistic and allegedly complete understanding of the world, ultimately committing to a deep fantasy of exterminating the very concept of loss. Even if history has adequately proved the impossibility of circular machines, the hubris of imagining the world without resistance is resurging: from denying the friction against motion to denying the black holes of recirculatory processes. While the journey to outer space spawned an unprecedented enthusiasm for the boundlessness of outer space, the desire for domination and expansion of power was relocated in fine-tuning the recirculation of planetary material resources.

On the other hand, that same desire for recycling matter endorsed material and organisational techniques as a new scientific site of exploration and laid the groundwork for the articulation of new perceptions of materiality. We may perceive the materials that undergo a recycling process as "semi-fluids" and "semi-substances" as they dissolve into their constituents and are reprocessed into new states. Materials in the recycling process signal more than themselves, the process of their own transformation. Therefore, the idea of recycling in closed systems reflects more than the unending conversion of material organisations; it reflects a conceptual system of viewing the world as currents of flow, rather than an accumulation of discrete objects.

The delineation of borders in the case of the closed system is at the same time a highly restrictive, but also a resourceful, model of creative production. In other words, the closed system speaks to the invention that might take place within the conceptual perimeter of a circle. The internal circulation and recirculation of matter and ideas within a defined radius and circumference was a theme with various reflections in the culture of the 1960s and 1970s. It began with the enclosed, finite earth, migrating to enclosed spacecraft as vehicles of extending and carrying life into non-living environments, and to recirculatory households as self-reliant ecosystems; finally, it came to signify a conceptual apparatus for the paradoxical nature of the design process.

Closed worlds depict in many respects how the whole earth icon emerged as an idealised representation of collective faith and imagination. While studying the earth as an object with contained resources, nature was sampled, systematised, and replicated through technological mediation. What became important in this process was the function of the system's parts and its subcomponents, tentatively assembled together. In the closed systems, complexity was not produced by the genius, inspiration, determination, or evolution of an architectural idea, but by modest actions of simple organic substitutions, which could not be caught up in any mystique of creation. At the time, this was a telling blow to the architect's training that demanded the comprehension of whole objects, always striving for systems synthesis, rather than systems analysis. It signalled a crisis where the object of the discipline underwent a fundamental de-appropriation of its normative tools. The vision of an enclosed interiority placed in extreme uninhabitable worlds would never become the space of the future, replacing and deleting the architecture of the past. But it did produce effects that have intrigued architects and designers ever since and sentenced a repertoire of research techniques, a set of tools for thinking of the design process and a language that established the evolving basis of today's experimental practice.

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About the Author: *Lydia Kallipoliti* is an architect, engineer, and scholar, currently an Assistant Professor at Rensselaer Polytechnic Institute. She has previously taught at Columbia University, Syracuse University, and the Cooper Union, where she was the Feltman Chair in Lighting and a Senior Associate at the Institute of Sustainable Design. Her research focuses on material experimentation, recycling, and the intersection of cybernetic and ecological theories in the twentieth century. She is the founder of *EcoRedux,* an innovative online research database, and the principal of ANA*cycle* studio in Brooklyn, New York. Her writing and design work have been exhibited internationally. Kallipoliti holds a SMArchS from MIT and a PhD from Princeton University.

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NOTES

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