Buckminster Fuller's Dymaxion House as a Paradigm for a Space Habitat

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Abstract

Buckminster Fuller's Dymaxion house introduced a new, integrative way of thinking about architecture. Fuller approached the totality of climate, environmental control systems, floor plans, interior design, materials, protection from the weather, structure, and utilities, as an integrated whole. With the aim of gaining maximum advantage from minimal energy input, Fuller discovered ways of lightening the inside of a house, thus mobilizing the way of living. In the conventional house, the choice of materials and structure dictated nearly the totality of dwelling. However, Fuller experimented with new and highly innovative ways of combining the principal subsystems.

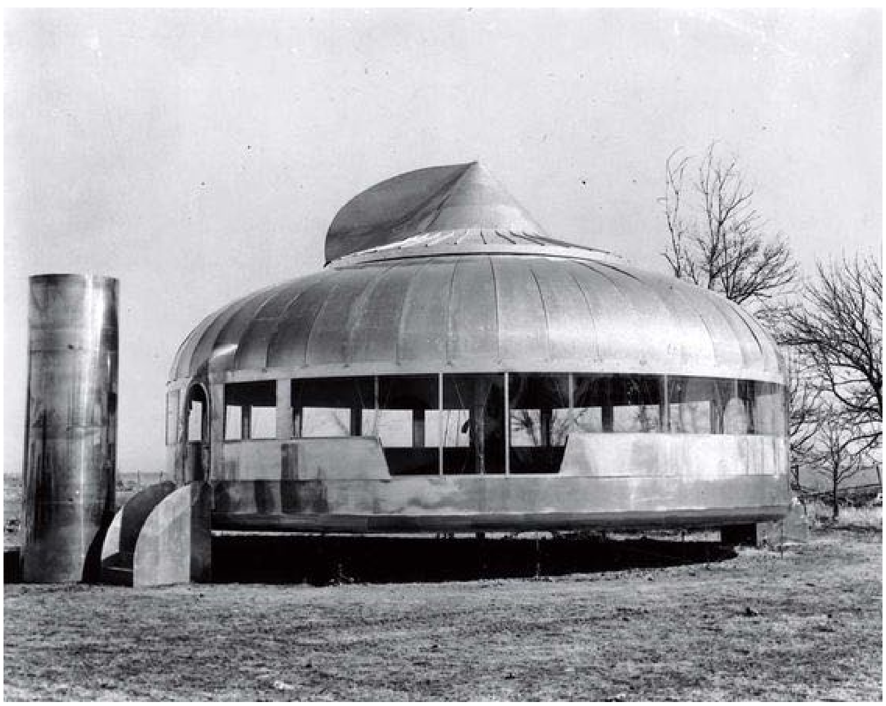

FIGURE 1. Photo of the Dymaxion House after the structural frame and cladding was assembled in Wichita Kansas, USA, 1946

1. Introduction

When Buckminster Fuller first presented the Dymaxion House to the public in 1927, he famously and provocatively asked "How much does your house weigh?" It was the same year that Charles Lindbergh flew across the Atlantic in the *Spirit of Saint Louis,* the structure of which was fabricated from aluminum struts covered with specially treated fabric. In this context, the all-aluminum "fuselage" of the Dymaxion House may be considered more advanced than the fuselage of the Spirit of Saint Louis. The aluminum Dymaxion House would weigh about three tons, "freight on board" from the factory. That mass compared to conventional dwellings weighing typically at least 1.5 orders of magnitude more. Fuller was making the point that using aviation fabrication techniques, it would be possible to mass-produce and deliver a much more economical and repeatable house.

For Fuller, the design did not entail an aesthetic problem; rather, it is the implication of different architecture elements' logical integrity. Like Dymaxion House, space habitation should be seen and designed as an interconnected system to support astronauts' life and well-being.

The Dymaxion House constitutes a remarkably complex and sophisticated solution to the post-World War II housing crisis and immense surplus aircraft manufacturing capacity. To distill the design philosophy that Buckminster Fuller expressed in the Dymaxion House into one sentence, it might be "Start from considering the totality of the design problem."

This paper does not approach the Dymaxion house as a literal *analog* to space habitats in the sense that it offers similar characteristics to a lunar or planetary base. Rather, it presents the Dymaxion house as a *paradigm* for an innovative way of thinking that sees all the subsystems as intimately interrelated. Utilizing the structural principles of strength in curved sheet metal, lightweight materials, and tensegrity it establishes a logic for integrating space habitat architecture. Through this *paradigm of integrative thinking,* it becomes possible to adopt a better, more comprehensive, and integrated approach to designing a space habitat.

There now exists a substantial literature on the design and construction of space habitats, both for microgravity spacecraft, including space stations, and lunar and planetary surface bases. However, the *independent* literature about the Dymaxion House and other of Fuller's inventions is not nearly so extensive. This distinction arises from the indisputable fact that nearly all the literature on Fuller's work has been written by advocates and enthusiasts of his work. In this sense, it is similar to the Space Architecture literature on space habitats, bases, colonies, settlements—whatever is the politique term of the moment; space exploration enthusiasts write nearly all of them. However, there is a growing critical approach to the Space Architecture literature in which the authors critique not only the work of others but also their own work. This critical approach—from the inside of the discipline—is new and late-coming to Buckminster Fuller's oeuvre.[1]

2. Understanding the Dymaxion Design Principle and Other Fullerisms

One of the challenges in comprehending Buckminster Fuller's design work — both practical and mathematical — is how to connect it to his theoretical arguments. It is too easy to get caught up in what have become buzz words: Dymaxion, Ephemeralization, Synergetic, Spaceship Earth, and so on, without grasping their empirical and experiential underpinnings. Fuller discusses his *Dymaxion Principle* in many places in his work in multiple different ways. Perhaps his most succinct definition appears in Synergetics 2, published the year after his death.

> The Stone Age logic said that the wider and heavier the walls, the more happily secure would be the inhabitants. The advent of metal alloys in the 20th century has brought an abrupt change from the advantage of structural ponderousness to the advantage of structural lightness. ***This is at the heart of all ephemeralization: that is the DYMAXION PRINCIPLE of doing ever more with ever less weight, time, and ergs per each given level of functional performance.*** With an average recycling rate for all metals of 22 years, and with comparable design improvements in performance per pound, ephemeralization means that ever more people are being served at ever higher standards with the same old materials (Emphasis added by authors. Fuller, 1983, pp. 174-175).

But the Dymaxion Principle derives from still deeper roots, which Fuller recounts in a discussion with Dr. Jonas Falk in the mid-1950s, soon after the success of his polio vaccine.

> Dr. Falk said, "I've always felt that those dymaxion gadgets—cars, houses, maps, etc.—were only incidental to what you really are interested in. Could you tell me what your work is?"
>
> I said, "Yes, I've been thinking about that definition for a long time. I've been engaged in what I call ***comprehensive anticipatory design science***."
>
> And Dr. Falk said, "That's very interesting, because that's a description of my work too" (Original emphasis. Fuller, 1965, p. 63).

So, Fuller's approach to the *Dymaxion Principle* stands on these three dynamics:

- **Comprehensiveness**—seeing the big picture, the integrated system with all it entails,

[1] Full disclosure: author Marc Cohen has been a lifelong adherent of Bucky Fuller, who attended many of his lectures, listened to many recordings of him speaking, spoke to him on multiple occasions, and corresponded with him. Now that the youthful enthusiasm has waned, it becomes possible to approach Fuller's achievements with fresh eyes, and to question some of the axioms and postulates of his reasoning.

- **Anticipation**—foreseeing what the building, the house, the invention, the operation, the system will need in its full development, and
- **Design as Science**—the idea that not only should there be a rational and empirical basis for design decisions, but that it should derive from a testable and provable basis.

Given the thousands of pages Fuller published on these topics, it would be easy—but unnecessary—to devote many more pages to exploring these precepts and principles, with one caveat. Fuller's notion of Design Science stands on the argument that it should be testable and provable, but it does not go so far as his 20th century contemporary philosophers of science. These contemporaries (e.g. Feyerabend, Kuhn, Popper) addressed the argument and principle in the scientific method that a scientific theory or hypothesis must be *falsifiable* not that it should be *provable*. Having said that, Fuller's idea of Design Science takes architectural practice far beyond the dilemmas about beauty, geometry, harmonics, mathematics, and proportion that Pérez-Gomez characterizes as occurring in *Early Modern Architecture* (Pérez-Gomez, 1988, pp. 163-267). Nor does Fuller's Design Science comport with Modern Architecture in the tradition of the Bauhaus or other 20th century masters. Fuller rejected emphatically the Bauhaus-inspired "International Style" (Fuller, 1965, p. 9) and offered this explanation:

> The international style thus brought to America by the Bauhaus innovators demonstrated a fashion inoculation effected, without necessity of knowledge of the scientific fundamentals of structural mechanics and chemistry, . . . (Fuller, 1965, p. 29).

Fuller criticized the "going design blindness . . . in the United States" that made Americans susceptible to the "more appealing simplicities of the industrial structures which had inadvertently earned their architectural freedom." Fuller argues that the true basis of the international style (applying to both Le Corbusier and the Bauhaus) is that the European architects developed it not for aesthetic innovation "but through profit-inspired discard of economic irrelevancies." He goes on to elaborate the financial basis of Modern "stylism:"

> . . . through economic spontaneity of engineering cost limits, that new factory design revolution which had a quarter of a century later such superficial appeal to the European architects as a functional style formula.
>
> . . . The international style's simplification was then but superficial. It peeled off yesterday's exterior embellishment and put on instead formalized novelties of quasi-simplicity permitted by the same hidden structural elements of modern alloys which had permitted the discarded *beaux-arts* garmentation (Fuller, 1963, pp. 29-30).

This recitation of Fuller's separateness from the predominant 20th century architectural movement, the Modern Movement, is important to establish to avoid the all too common academic categorization that lumps in the geodesic dome, the Dymaxion House, and tensegrity structures with stylistically-driven "movements" such as late-modern, post-modern, and deconstructionist trends. However, it would be inaccurate and unfair to leave the impression that Fuller had no concerns about the aesthetics of the built environment. On the contrary, the interior design of the Dymaxion House shows an intense focus on the quality of that living environment.

Having stated that, no glossary of Fullerian design terminology would be complete without the definition of synergy, perhaps the most misunderstood in his lexicon. The canon of Dymaxion design gives this set of definitions, drawn by Amy Edmondson from Synergetics (Fuller, 1982).

101.01 Synergy means behavior of whole systems unpredicted by the behavior of their parts taken separately.
102.00 Synergy means behavior of integral, aggregate, whole systems unpredicted by behaviors of any of their components or subassemblies of their components taken separately from the whole.
962.40 Synergetic geometry embraces all the qualities of experience, all aspects of being.

This set of definitions raises an obvious question, but not one that Fuller apparently asked out loud: What does *prediction* mean? More particularly, what does *unpredicted* signify? Fuller explains how the term synergy derives from the formulation of metal alloys. (Fuller, 1963, pp.). However, if one has a strut from a geodesic dome or a hub of that dome that ties struts together, is it truly unpredicted or unpredictable that a multiplicity of them could form a Platonic or Archimedean solid, much less a triacon geodesic dome or vector equilibrium "jitterbug?" The next step in this interrogatory is to ask whether Dymaxion designs are truly synergetic. Could one argue that taking any one element from the Dymaxion Car, House, or Map would render the whole of that product *unpredicted?* And unpredictable to whom? This line of inquiry veers into the realms of both archeology and futurology. It becomes a cognitive question: what is the knowledge base of the person trying to interpret or to predict the behavior of the whole system of which this element is a part.

3. Lunar and Planetary Habitats

The critical distinction between the Dymaxion House and nearly all concepts to date for lunar and planetary base habitats is the Dymaxion House addressed all the major systems and subsystems whereas these lunar and planetary habitat designs are almost entirely "one-trick ponies." This expression means that these habitat concepts are each optimized for one or possibly two attributes or functions, while taking an attitude of "benign neglect" toward all the others. It is not necessary to provide a detailed examination of extant habitat concepts to observe that the "one-trick" for which they optimize are typically:

1. Integration with a lunar or Mars lander vehicle,
2. Use of ISRU materials to build a structure in situ (e.g. using primarily robotic 3D printing),
3. Use of ISRU materials or geological features to provide radiation and micrometeoroid protection, or even worse,
4. Integration as a dual use interplanetary vehicle/landed habitat (Cohen, 1996a; Cohen, 1996b).

This analogy as applied to a house on Earth would be to design the house with walls and roof, but no climate control (heating, ventilation, air conditioning, or even windows for "natural light" and "natural ventilation"). This analogy frames the shortcomings of most lunar/planetary habitats. This analogy may apply equally to the design of space station habitation modules because of the pre-determination of the primary structure pressure vessel from:

1. A launch vehicle propellant tank (i.e. Skylab)
2. A volume and configuration determined by the delivery truck (i.e. the Space Shuttle cargo bay),
3. A "fat tire" inflatable habitat with all the functions within the interior "axle" or cantilevered off it (e.g. TransHab and its derivatives), or
4. The adoption of a flight vehicle to a fixed module (i.e., the Cygnus cargo module as habitat for the Lunar Gateway Station).

What is so different about the Dymaxion House is the way in which Bucky Fuller thought through all the "subsystems" and implemented them in an integrated and mutually sustaining and supporting manner, as a mostly unified whole.

4. Comparison of Dymaxion House Systems to a Space Habitat

The 1998 SAE paper "Space Habitat Design Integration Issues," (Cohen, 1998) applied the then-current 16 Division Masterformat® from the Construction Specifications Institute (CSI) to elucidate the subsystems commonly required to create a successful space habitat. Since that writing, the CSI has expanded Masterformat® to add a variety of new, more technology-oriented Divisions (CSI, 2020). TABLE 1 presents the relevant attributes of the Dymaxion House in coordination with a comparison of this newest 2020 edition to the 1998 version, so the reader can track it in both CSI versions.

Besides adding some new topics, the most notable change appears to be that the CSI subdivided both the Division 15 Mechanical Systems and Division 16 Electrical Systems into multiple new divisions. These changes afford a measure of refinement in the precision of the corresponding specifications.

FIGURE 2 shows the 1946 Dymaxion House floor plan. The plan divides the 102.2 sq. m (1100 sq. ft.) of floor area approximately in half between the two bedrooms (and their accessory enclosures) at the top and the living room, kitchen and "entry hall" (which leads nowhere) in the lower half. Each bedroom connects to its own completely prefabricated metal bathroom. There are four of the oblong, curve-sided quasi-rectangular stowage wall units with radiused corners. The kitchen occupies half of the storage unit adjacent to the living room. In the original scheme, the bedrooms were separated from the other areas, and from each other by accordion doors. The two exterior doors occur on nearly opposite sides in the lower half of the less private rooms. What this plan does not show is where the oil-burning furnace and HVAC unit was installed adjacent to the central mast.

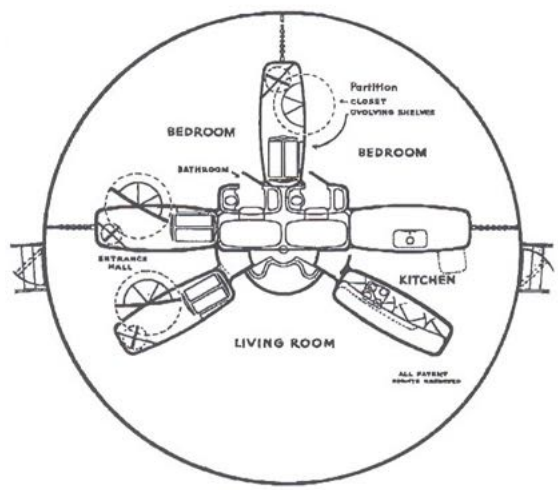

FIGURE 2. Dymaxion House floor plan.

TABLE 1. Dymaxion House Compared to Space Habitats 1 of 3				
1998 CSI Masterformat®	**2020 CSI Masterformat®**	**Comparable Space Habitat Subsystem/ Discipline**	**DYMAXION HOUSE**	**Comments**
1. General Provisions	0100 General Conditions	System Engineering	Integrated Systems Approach	2020 adds 0180 Performance Requirements FIGURE 1.
2. Site Planning and Site work	0200 Existing Conditions	Planetary protection, avoidance of forward & back contamination	Assumes a mostly flat site.	FIGURE 2.
	3100 Earthwork	Site prep using grading robots?	Assumes earthwork primarily for site drainage.	
	3200 Exterior Improvements	N/A?	Occupant is free to plant flora.	
3. Concrete	0300 Concrete	Lunar regolith concrete or Mars sulfur concrete	Concrete footings for steel posts, below frost line.	FIGURE 3.
4. Masonry	0400 Masonry	Radiation shielding, thermal stabilizing?	Not compatible, except perhaps for fireplace.	FIGURE 4.
5. Metals	0500 Metals	Aluminum pressure vessels/primary structure	Primary structural and enclosure against weather & climate.	FIGURE 5. Potential ISRU production of metals.
6. Wood, Plastics, and Composites	0600 Wood, Plastics, and Composites	Composite pressure vessels/primary structure & many uses for plastic, including window protection.	Wood in hardwood floors, plywood partitions, selected finishes. Windows: acrylic, Plexiglas, or polycarbonate.	Polyethylene-Z for radiation protection FIGURE 6.
7. Thermal and Moisture Protection	0700 Thermal and Moisture Protection	Thermal insulation is conventionally MLI	Aluminum shell provides moisture protection; thermal properties, protection from insulation in roof & walls.	FIGURE 7.
8. Doors and Windows	0800 Openings	Pressure hatches, windows/cupolas	Doors are hatch-like with semi-circular top & flat bottom. Plexiglas windows.	FIGURE 8.

TABLE 1 Dymaxion House Compared to Space Habitats 2 of 3				
1998 CSI Masterformat®	**2020 CSI Masterformat®**	**Space Habitat Subsystem**	**Dymaxion House**	**Comments**
9. Finishes	0900 Finishes	Fire-resistant, acoustical, durability properties are important. Space-rated interior paint colors are still limited by high cost of safety testing.	Coatings on aluminum & some plywood laminates plus stainless steel in kitchen, besides metal unit kitchen. Sound transmission between rooms through the thin walls and over them would pose a concern for finishes.	Addition of Absorptive materials would improve acoustical comfort of both space habitats and Dymaxion House. FIGURE 9.
10. Specialties	1000 Specialties	Safety specialties including Fire safety; Stowage lockers/racks.	The "O-volving" shelves and rotating closet. Integrated stainless steel countertop/ stove/sink in kitchen.	Conventional "rack functional units" derive from ISS. FIGURE 10.
11. Equipment	1100 Equipment	Laboratory & Medical equipment Appliances for cooking, laundry	1130.13 Residential Appliances 1132.13 Metal Unit Kitchen	A leading issue in space is multiuse equipment. FIGURE 11.
12. Furnishings	1200 Furnishings 1210 Art	Habitat interior outfitting may be integral to the plan layout.	Rooms are laid out in radial fashion around the central structural & utility core, built-ins must conform to this geometry. Movable furniture aligns with walls.	Includes room definition as finished surfaces delineate them. FIGURE 12.
13. Special Construction	1300 Special Construction 1321 Controlled Environment Rooms for Astrobiology Labs 1331 Fabric Structures (Inflatables), 1348 Sound & Vibration Controls	Controlled Environment Rooms for Astrobiology Labs, Fabric Structures (includes Inflatables), Internal sound absorption, vibration isolation at sources & between modules 1349 Radiation shielding from ISRU materials or from low-Z materials.	1334.23 Fabricated Manufactured Metal Buildings – could cover the whole Dymaxion shell and structural system	Applies generally to space lab modules. The Radiation shielding requirement will add material changes and increased mass to the design. Acoustical control and protection can apply as special construction for both space habitats & Dymaxion House. FIGURE 13.

TABLE 1. Dymaxion House Compared to Space Habitats 3 of 3				
1998 CSI Masterformat®	**2020 CSI Masterformat®**	**Space Habitat Subsystem**	**Dymaxion House**	**Comments**
14. Conveying Systems	1400 Conveying Systems	Could apply to transport of scientific samples through an airlock, into a lab, and around the lab.	The Ovalator shelves are a *kind* of conveying system.	FIGURE 14.
15. Mechanical Systems	2100 Fire Suppression Systems 2200 Plumbing Systems 2300 Heating, Ventilating, and Air Conditioning (HVAC)	ECLSS, Fire Suppression, Plumbing, Hygiene facility, toilet, prevention of forward-, back -, & cross- contamination.	No sprinklers. Plumbing for kitchen & bathroom with one-piece sink/tub/toilet. Central heating/ cooling in the utility core, with ducted ventilation. The inside-the-wall rain drainage system can collect & send water to a cistern.	FIGURE 22. FIGURE 23.
	4400 Pollution and Waste Control Equipment 4600 Water and Wastewater Equipment	Recovery of H2O from urine, condensate, graywater, blackwater. Reuse or disposal of excess brines.	Connects to conventional septic or sewer system, but could integrate advanced ECLSS technology.	Belongs with mechanical systems and plumbing.
16. Electrical and Data Systems	2500 Integrated Automation	Essential to operate the systems & detect, diagnose, & correct faults in them	Could be a candidate for "smart house" automation & regulation systems.	Significant that Integrated Automation appears before Electrical Systems
16. Electrical and Data Systems	2600 Electrical Systems	Power & data lines are the neurons & circulatory system	Part of integrative design, constrained by interior radial geometry Electrical Power distribution radiates from utility core through radial walls and under the floor.	FIGURE 16 shows electrical conduits bundled around the central structural steel mast.
16. Electrical and Data Systems	2800 Electronic Safety & Security	Essential part of 2500	Could be applied to D. House.	

5. The Dymaxion House, Reconstructed and Rehabilitated in the Henry Ford Museum

Jay Baldwin worked for decades as a construction engineer and leader for Bucky Fuller. Here is his intimate account of the Dymaxion House as it appears on the Buckminster Fuller Institute's (BFI) website:

> Conceived and designed in the late 1920's but not actually built until 1945, the Dymaxion House was Fuller's solution to the need for a mass-produced, affordable, easily transportable and environmentally efficient house. The word "Dymaxion" was coined by combining parts of three of Bucky's favorite words: DY (dynamic), MAX (maximum), and ION (tension). The house used tension suspension from a central column or mast, sold for the price of a Cadillac, and could be shipped worldwide in its own metal tube. Toward the end of WW II, Fuller attempted to create a new industry for mass-producing Dymaxion Houses.
>
> Bucky designed a home that was heated and cooled by natural means, that made its own power, was earthquake and stormproof, and made of permanent, engineered materials that required no periodic painting, reroofing, or other maintenance. You could easily change the floor plan as required - squeezing the bedrooms to make the living room bigger for a party, for instance.
>
> Downdraft ventilation drew dust to the baseboards and through filters, greatly reducing the need to vacuum and dust. O-Volving Shelves required no bending; rotating closets brought the clothes to you. The Dymaxion House was to be leased, or priced like an automobile, to be paid off in five years. All this would be possible now if houses were engineered, mass-produced, and sold like cars. $40,000.00 sounds about right.
>
> In 1946, Bucky actually built a later design of the Dymaxion House (also known as the Wichita House). ***I had the honor to lead a bunch of volunteers that took it apart in 1992.*** It was mostly intact despite being abandoned (except for the incumbent herd of insolent, astoundingly filthy raccoons) for several decades. The 747 First-Class ambiance was faded and smelly, but you could still sense the elegance of a living room with a 33-foot window.
>
> The Dymaxion's round shape minimized heat loss and the amount of materials needed, while bestowing the strength to successfully fend off a 1964 tornado that missed by only a few hundred yards. And the Dymaxion only weighs about 3000 pounds versus the 150 tons of an average home! (emphasis added by authors, Buckminster Fuller Institute, based on J. Baldwin, 1997, https://www.bfi.org/about-fuller/big-ideas/dymaxion-world/dymaxion-house).

5.1 General Conditions & Performance

CAVEAT: Although Fuller first conceived or the earliest version of the Dymaxion House in 1927, (with the hexagonal floor plan) this paper addresses only the prototype that he succeeded in building in 1946. This version has a circular plan, curved roof, and is fabricated from steel and aluminum using then-state of the art manufacturing techniques.

This section presents the main photo-documentation of the Dymaxion House as installed in the Henry Ford Museum in Dearborn, Michigan.[2] It follows the CSI Masterformat® presented in TABLE 1 above. The reason for presenting the sequence of photos in this manner is to avoid making assumptions about how Fuller conceived the design. It particularly avoids presenting it as either a traditional aesthetic formulation or as, for example, a Beaux-Arts approach via *une promenade architecturale.*

Instead, using the Masterformat® facilitates presentation of the Dymaxion House as a carefully selected and integrated system of many functional subsystems. By following this standard outline, it prevents the authors from making unsupported assumptions about the order in which Fuller conceived the design or how he may have prioritized its subsystems. FIGURE 5.1a shows the Dymaxion House as presently installed in the Henry Ford Museum. IT shows the entry door (at least in terms of museum traffic) on the right side and the people are exiting down the curving ramp from the exit door diametrically opposite. At the top appears the distinctive curl of the ventilator, a novel solution to ensure fresh air circulation using gravity flow. The windows reflect a bit of the modernist aesthetic of Le Corbusier's *fenetres en longeur,* "windows in length" or in the poorly translated version, "strip windows" as an alternative to windows that are "punched holes." A view of the living room window on the other side in FIGURE 5.1b shows a continuous strip of plexiglass windows about 10 m long around the perimeter.

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[2] All photos by Marc M. Cohen, November 2019, unless noted otherwise.

FIGURE 5.1a. Dymaxion House as installed in the Henry Ford Museum, Dearborn, MI.

FIGURE 5.1b shows the exit door with its semicircular arched frame and the 10 m continuous strip window of the living room to the left.

5.2 Site Planning and Earthwork

FIGURE 5.2 shows the original site of the Dymaxion house, on a lake near Wichita, KS. FIGURE 5.2a shows a scale model of the house with landscaping. What appear to be white limestone flags placed in a circle about the house provides both a footpath and probably a perimeter drain system. FIGURE 5.2b shows a view of the house from the road. FIGURE 5.2c reveals the much more elaborate and visually rich treatment of the lower level in the back, facing on the lake. Developing this site would have involved a substantial amount of earthwork, especially to excavate the basement space under the house that faces out on the lake.

FIGURE 5.2a. Scale model of the Dymaxion House showing the front entrance facing the front yard and the street.

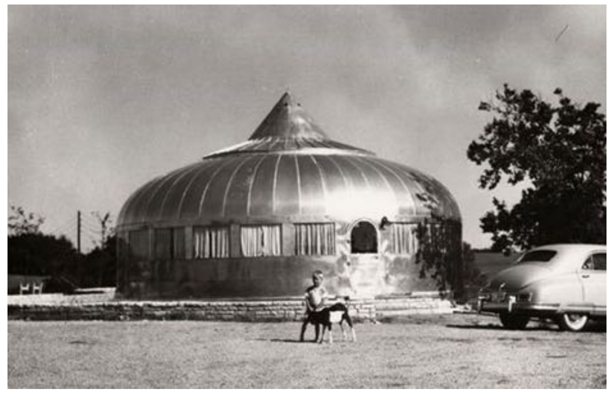

FIGURE 5.2b. View of the Dymaxion House from the street showing how the white limestone circle is raised above grade and the ventilator faces the lake in back, circa 1950.

FIGURE 5.2c. View of the lake side of the Dymaxion House at Rose Hill, Wichita, showing the lower level basement and deck, with retaining wall to the right and what appears to be native rock to the left, circa 1950.

5.3 Concrete

Concrete does not play a prominent role in the design concept for the Dymaxion House. The minimum requirement would have been to provide footings or piers for the vertical steel posts that support the floor deck of the house. Piers are more likely, given their presence on the lakeside. FIGURE 5.3a shows where these posts occur under the building, raising and levelling the perimeter ring-beam. Note the diagonal tension members that radiate from the post to secure the perimeter floor beam. This post has a wider base through which anchor bolts would secure it to the concrete pier. FIGURE 5.3b shows the anchorage of the central mast base plate, which would be torqued down to anchor bolts in a substantial, cylindrical concrete pier.

Concrete would play a larger role in developing the lakeside landscaping. The retaining wall surely consists of a reinforced concrete wall with a very large footing behind the squared and faced stone veneer. Also, note the rectangular. concrete piers that support what appears to be a wood deck, but may alternatively consist of a concrete plate.

FIGURE 5.3a Detail of the typical steel leveling post supporting the Dymaxion House Structure

FIGURE 5.3b Detail of the central mast base plate and anchorage, to a concrete pier.

5.4 Masonry

Masonry plays no significant role inside the Dymaxion House. The only conceivable application would be the fireplace in the living room, but that appears to consist of all metal components. Masonry does appear to provide a design element in the lakeside retaining wall, unless what appears to be stone fascia was actually just textured concrete.

5.5 Metals

Metals—aluminum and steel—serve the dominant role in the structural and moisture protection system (the walls and roof). The structural system provides a visual and functional focus for the architectural plan around the steel central mast from which the roof is suspended. The mast is cable-stayed and stiffened by lateral struts that reach out to receive the guy wires that are in tension. FIGURE 5.5a shows a detail of the central mast. FIGURE 5.5b shows

FIGURE 5.5a. Detail of the central mast with stand-off struts that hold the guy wires that help to stiffen the mast.

The central mast rises to near the peak of the ventilator. FIGURE 5.5b shows the mast from the floor level to its top. The slenderness ratio is visually quite striking, especially considering that electrical conduits are bundled all around it. From the mast's peak, the entire roof structure is suspended.

FIGURE 5.5b. Full height of the central mast, from the floor level up into the ventilator.

The tension members that stiffen the walls pass across the windows and so become a highly visible part of the Dymaxion House aesthetic. FIGURE 5.5b shows an example of these diagonal tension rods between an exterior door and a window.

FIGURE 5.5b. Example of tension rods in the outer wall, between a doorway and a window.

FIGURE 5.5c presents a drawing of the structural system, which consists primarily of the leveling posts, the perimeter floor beams, and the top of perimeter wall hoop/beam, plus the center mast. Steel tension members tie together all these structural elements in a quasi-tensegrity structure scheme.

5.6 Wood, Plastic, and Composites

The Dymaxion House makes extensive use of wood—mainly plywood and veneers—plus hardwood flooring to create a warmer feeling in the interior. It was also Fuller's intent to make extensive use of the new revolutionary material: plastics. The most prominent use of plastic is in the Plexiglas® windows. During the Second World War that ended just the year before erecting the Dymaxion House, Plexiglas® enjoyed tremendous success in the fabrication of cockpit canopies and other curved windows for military aircraft. Other applications or uses of plastic are rather lacking in available documentation at this time, however, Fuller wanted to use synthetic fabrics such as *naugahide* in the furnishings.

FIGURE 5.6 shows a cutaway mockup displaying the use of construction grade plywood and veneered finish-grade plywood. This particular application to a curved wood framework created the stowage walls that adjoined each bedroom on one side and the living/dining room on two sides. The view through the storage unit reveals the kitchen, built into a similar stowage wall assembly.

FIGURE 5.6. Cutaway view of a storage wall unit "under construction, with an inner sheath of presumably structural-grade plywood and an outer sheath of dark red cherry or mahogany veneer plywood.

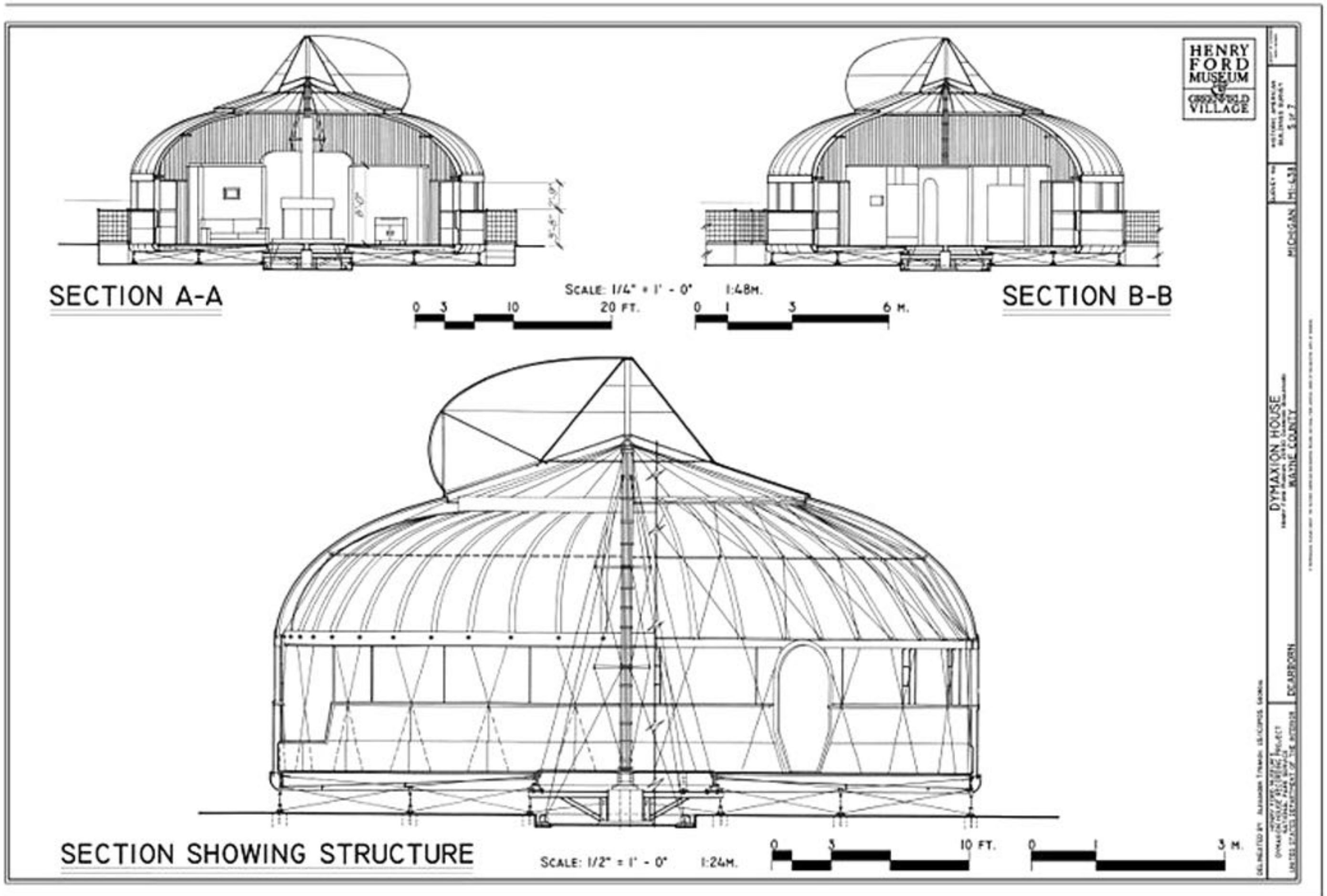

FIGURE 5.5c. Elevation and Section Elevation Drawings for reassembly of the Dymaxion House at the Henry Ford Museum. Courtesy of the Henry Ford Museum. It shows how the central mast rises to the implied peak of the roof inside the ventilator shell. The tension rod “X-braces” appear all along the outer wall. The radially-ribbed arrangement of the aluminum roof panel structure shows how it appears to suspend the perimeter wall hoop, which the X-braces hold in position.

5.7 Thermal and Moisture Protection

The aluminum shell comprising the roof and walls provides the thermal and moisture protection. From the reconstructed house, it is difficult to discern the extent to which the design included thermal insulation. However, in the section of the ceiling that is open from below to see the underside of the aluminum cladding, a foil insulation layer is present, suggesting the earlier presence of roll or batt insulation. FIGURE 5.7 shows this thermal protection layer.

FIGURE 5.7 The section with the under-panels of the ceiling removed show the construction of the roof cladding with ribs that span from the top of wall perimeter hoop to the top of the central mast. It also shows the foil sheets that suggest where roll insulation would be installed.

5.8 Openings: Doors and Windows

To create the Dymaxion House successfully, Fuller needed to create his own, unique system of fenestration which he largely integrated with the window-walls and door frames. There are two exterior doors, exterior views of which appear in FIGURES 5.1a and 5.1b. FIGURE 5.8a and 5.8b show the interior features of a doorway and door in closer detail. The inward chamfering of the door frame appears somewhat idiosyncratic, insofar as there is no obvious reason for it. It adds complexity and material to the doorframe, while reducing the clear passage space to carry large or bulky objects through it.

The fabrication of the door uses much the same square tubing as the doorframe except that the door window is double-glazed with Plexiglas®. The lower panel of the door appears to be made from Masonite particle board.

FIGURE 5.8a. Interior view of an exit doorway.

FIGURE 5.8b. Detail view of an exterior door frame and door.

The Dymaxion windows come in two types: squarish frames with lites and the nearly frameless *windows in length* that run around the living/dining room and the circulation passage. Since the living/dining room occupies roughly a third of the total floor area, its continuous strip window is very dramatic. At the center segment, the frame widens down vertically, increasing the bay window effect. The diagonal cut in the wall suggests an abstraction of the traditional bay windows from Fuller's New England upbringing in Massachusetts and Maine. FIGURE 5.8c shows this living room window wrapping around nearly a third of the house's perimeter. FIGURE 5.8d shows a similar design but to less dramatic effect along the corridor. Although most of the windows in the two bedrooms are square, this segment of corridor with the *window in length* adds a subtle visual effect that enlarges the sense of space, of distance, of volume.

FIGURE 5.8c. View of the living/dining room with the window in length and the lowered frame that creates a bay window effect.

5.9 Finishes

Fuller employed a variety of finishes in the Dymaxion House. Metals are the primary material inside and out, mainly aluminum. FIGURE 5.9a shows the several metal finishes at the junction between two rooms. This photo shows the sand-beige painted aluminum ceiling panel, the dull-polished corrugated aluminum partition above the accordion door, and the polished aluminum inside perimeter hoop and door frame.

Fuller made extensive use of wood for the storage unit walls and floor. The kitchen is finished in stainless steel and what appear to be painted metal cabinets. FIGURE 5.9b shows the varied but complementary finishes in the living room in a photo taken from adjacent to the fireplace.

FIGURE 5.9a. Interior metal finish materials above eye level in the corridor/circulation zone.

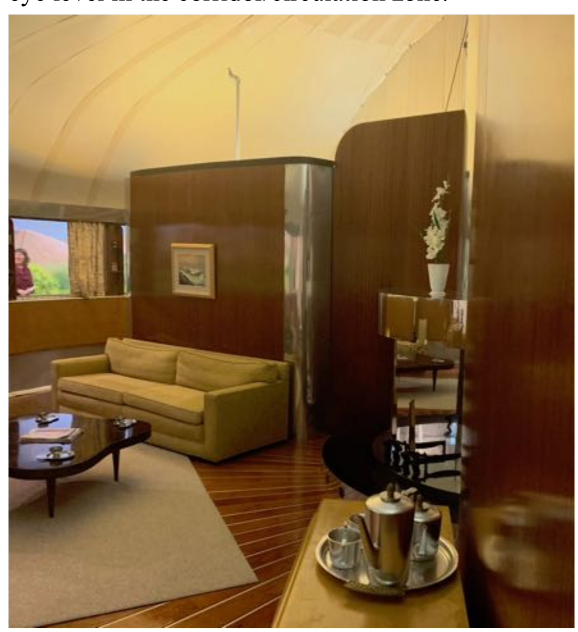

FIGURE 5.9b. Wood finishes in the living room, showing three different materials on the partitions, the floor, and the wainscoting on the perimeter wall.

5.10 Specialties

Fuller created two notable and unique "specialty" units in the Dymaxion House: the rotating closet and the "O-volving" shelves. Both these specialties are built into the oblong, slightly curved, wood-veneered storage units. The O-volving shelves appear in FIGURES 5.10a and 5.10b.

FIGURE 5.10a. A child demonstrates the easy use of the O-volving shelves by simply pressing the button, the shelf-trays revolve around a center track. The back door of the rotating closet appears beyond the people.

5.10b. The child discovers the back of the O-volving shelves, built into the storage wall unity.

The rotating closet is built into the oblong storage wall units, adjacent to the O-volving shelves. FIGURE 5.10c displays the rotating closet.

FIGURE 5.10c. Rotating closet specialty built into the oblong stowage wall unit. Note the wood veneer finish.

5.11 Equipment

In Masterformat® Fuller's kitchen design would qualify as a Metal Kitchen Unit *equipment*. It incorporates a monolithic stainless-steel countertop/sink/stovetop. The oven and refrigerator drawers are built into the lower cabinets as shown in FIGURES 5.11a and 5.l11b.

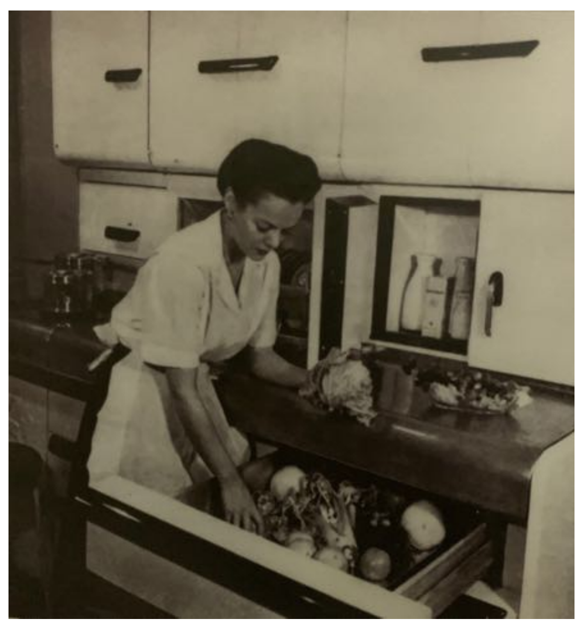

FIGURE 5.11a. An original occupant of the House opens the upper refrigerator drawer.

FIGURE 5.11b. The design and fabrication of this kitchen as unitized equipment was far ahead of its time. This photo shows it as it appears today, still avant-garde, particularly the continuous stovetop/counter/sink configuration.

5.12 Furnishings

One weakness of Fuller's architectural plan (FIGURE 2) is that there is little or nothing about the design of the principal rooms (2 bedrooms and the living/dining room) that would tell us what are their purpose or function. Largely, need to create a rigorous geometry to allocate the floor area and make it compatible—if not harmonize with the structural design—causes this lack of identity. In order to counteract this lack of identity, Fuller relies on the furnishings to give each room its particular identity and function. It may seem too glib to say that putting a bed into a bedroom gives it an identity or that putting a dining table and chairs into a dining area gives it an identity; ditto for putting a sofa into a living room. However Fuller pulls it off. He chose simple furniture with clean lines and no superfluous "garmentation" as he calls it in Ideas and Integrities. FIGURE 5.12a shows a bedroom area, with the bed moved against the outer wall. FIGURE 5.12b shows the furnishings that characterize the living/dining area. FIGURE 5.12c shows the fireplace at the center wall angle.

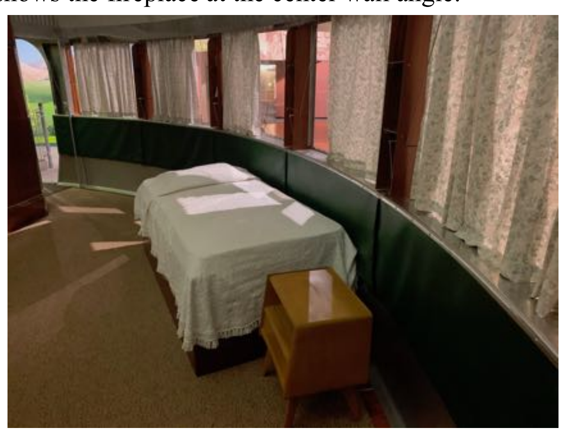

FIGURE 5.12a. Bedroom furnishing, looking through the accordion doorway toward the front door.

FIGURE 5.12b. Dymaxion House living/dining room furnishings.

FIGURE 5.12c. The fireplace is situated at the widest angle of the floor plan, providing the central focus. It provides an ancient symbol of home and hearth, despite its streamlined and mirrored form. Photographer unknown.

5.13 Special Construction

Division 1300, Special Construction, encompasses a vast range of structures and treatments designated for special purposes. Under the Masterformat®, the entire Dymaxion House, taken in total, would qualify as special construction, in much the same manner as a metal grain silo or a Quonset Hut. One treatment that would help both space habitats and the Dymaxion House would be acoustical isolation, absorption, and other forms of containment or mitigation.

5.14 Conveying Equipment

Conveying equipment generally refers to elevators, escalators, moving walkways, and dumbwaiters. Conveying equipment does not play a role in the Dymaxion House. Conveying equipment may find a role in some space habitat laboratories, particularly for moving samples with biological potential from sample airlocks to Biosafety Level (BSL) rated gloveboxes or handling chambers.

[Sections 15 through 20 are "reserved" in Masterformat®]

5.21 Fire Suppression

The original Dymaxion house was advertised as fireproof because of its predominant metal construction. However, it did not include a sprinkler system or any other active fire alarm or suppression. The current installation of the house in the HF Museum includes both alarm sensors and sprinklers, as shown in FIGURE 5.12b. The white pipe rising above the wall on the right is a sprinkler riser.

5.22 Plumbing

Probably the most famous component of the Dymaxion House is its one-piece, unitized metal bathroom, of which there are two. Fuller writes about how it spawned an industry in Europe, although the preferred material there was reinforced Fiberglas. FIGURE 5.22a shows "floor" plan view in a patent drawing of the one-piece bathroom. FIGURE 5.22b shows an axonometric drawing of the Dymaxion bathroom. FIGURE 5.22c shows a photograph of the poorly lit bathroom

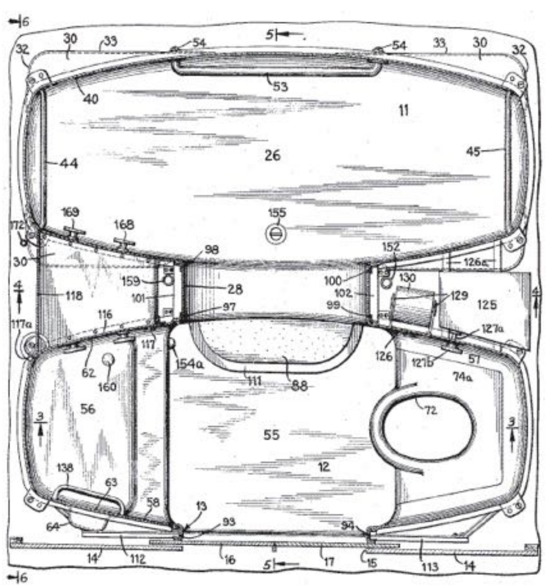

FIGURE 5.22a. Fuller Patent Drawing (1940). "Floor" Plan of the Dymaxion Bathroom.

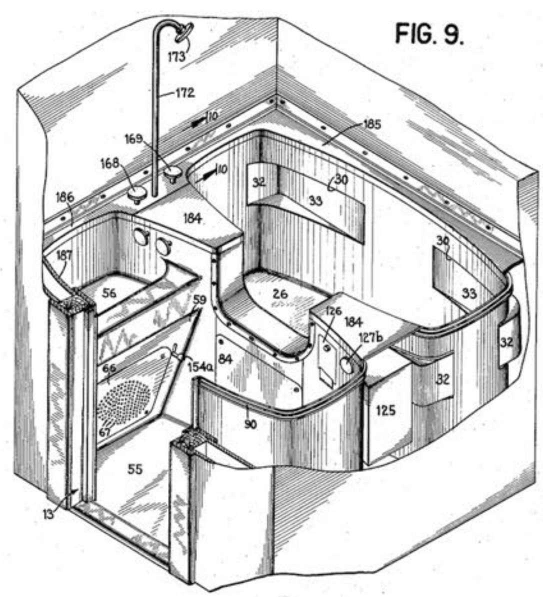

FIGURE 22b. Fuller Patent Drawing (1940). Axonometric view of the Dymaxion Bathroom

FIGURE 5.22c. Photo of the Dymaxion Bathroom in the same orientation as the 1940 patent floor plan. Sink is to the left, toilet is to the right, steps down into the bathtub are straight ahead.

5.23 Heating, Ventilating, and Air Conditioning

A major innovation in the original Dymaxion House was to install an oil-burning heating system. Up to that time and well into the 1950s, it was normative to heat houses with coal, which required shoveling coal at regular intervals into the bulky coal-burning boiler. The advent of oil-burning furnaces marked a major improvement in convenience, reducing the size and mass of the heating system substantially, and eliminating the coal dust before burning and the soot after burning. What made oil heat so attractive was its economic side. In the late 1940s and early 1950s, the cost of heating oil was typically \$0.05 or less per US gallon (or about \$0.012 per liter). FIGURE 5.23a shows the installation of the Heating, Ventilating, and Air Conditioning unit in the volume adjacent to the central mast.

The Dymaxion scheme called for circulating the conditioned air inside the ceiling plenum, through “hollow beams” under the floor, and even in the walls below the windows. It would be very interesting to uncover how successful these active ventilation distribution systems proved to be in operation. FIGURE 5.23b shows a museum display of “Ventilation Through the Walls,” but it was difficult to identify exactly where the air ducts ran.

FIGURE 5.23a. The HVAC units, painted yellow ochre, sit next to the central mast and down-feed conditioned air into ducts or “hollow beams” below the floor or in the floor plenum.

FIGURE 5.23b. Museum exhibit of "Ventilation through the Floor, and presumable distributed and diffused through openings or grills in the walls.

5.25 Electrical and Data Systems

The electrical power enters the Dymaxion House beneath the floor. The power cables and wires run vertically through conduits bundled around the central mast, as shown in FIGURE 5.5a. At some point these conduits branch sideways from the mast and enter the ceiling plenum between the roof cladding panels and the ceiling panels. From there, the conduits run down into the perimeter walls and into points of substantial consumption such as the kitchen.

6. Urban Context

One area where the Dymaxion concept does not meet the challenge of metropolitan or megalopolitan development is the urban planning implications of basing the layout of a suburb on the Dymaxion House. Certainly, the Dymaxion House demonstrated advantages in mass, materials, sustainability, and mass-production potential over conventional "stick-built," panelized, or mobile (trailer) homes. However, despite Fuller's development of the AirOcean Dymaxion World Map and the fundamentals of System Thinking, he never really questioned the land use pattern of traditional suburban tract housing.

FIGURE 6. Suburban "tract housing" site concept for Dymaxion House community development. Credit, Allegra Fuller Snyder, The Streaming Museum.
http://images.nymag.com/arts/art/features/houses080623_560b.jpg

What the authors find somewhat paradoxical about this shortcoming is that at the same time as he was advocating the Dymaxion Principle, he was also advancing his concepts for an "all-space-filling" synergetic geometry. This construct of "all-space-filling" geometry based primarily upon tetrahedra and octahedra poses a powerful alternative to the orthogonally-based right angle cube geometry that manifests from the gravity field of the Earth acting perpendicular to its surface. Granted, it would pose a huge complexity to try to design and build a true all-space-filling multiple dwelling unit building using the 1920s to 1940s aluminum-based aeronautical manufacturing techniques.

Despite Fuller's deprecation and thorough rejection of the International Style, there is one tenet of its ideology that he seems to accept uncritically. This tenet consists of the belief that for a style to become truly *international*, there should be one building form that an architect can place on any flat site, anywhere. As the pioneer of post-war factory manufactured housing, the Dymaxion House hewed to this credo.

6. Discussion

Interior Design Integration constitutes the domain in which Fuller's profound design insights become manifest. Fuller writes:

> "A home, like a person, must as completely as possible to be independent and self-supporting, have its own character, dignity, and beauty or harmony" (source?).

The Dymaxion house was one of the first houses of the Modern Era that turns away from the orthogonal plan and instead explores a systematic approach to a radial layout. This radial plan stems literally from the structural mast in the center from which the entire roof structure and top of wall perimeter band hangs.

The forms of Fuller's buildings, including domes and earlier versions of the Dymaxion house resemble industrial design pieces more than traditional residences, Fuller introduced the circle-shaped house with rectangular furniture that leaves the gaps between a subject and walls. This means that for this typology of a house, furniture must be developed and integrated into the idiosyncratic footprint of the floor plan. Fuller does not allow this contradiction with conventional furniture rectilinear shapes to compromise the purity of the structural and subsystem geometries.

Fuller's principles of living off-grid (as much as it could be possible at that time), the building being extremely lightweight and therefore mobile, and doing more with less summarize the Dymaxion House. have been The Institute of Design in Chicago's students in 1948 vividly applied these to his project with their Standard of Living Packaging. This project was a manifesto on household furnishing packaging that could be packed into a container and transported with a trailer. It was a box with collapsible walls that were fastened by hinges. When folded down, the walls also served as the floor for the household items as well as floor surface of the floor plan.

In much the same way, space habitats follow the best shapes determined by physics for pressurized vessels – cylinders, torus, pill shape. Both of these architectures require specifically designed pre-integrated interior elements for the best and most efficient use of the least amount of area and volume. This axiom applies equally to human behavioral health on Spaceship Earth and in human-made spacecraft.

NASA identified that the second biggest risk facing people living in space, after radiation, is behavioral health (source?). . Working and living in tiny space habitats, there is no runaway, no retreat, it is not possible to go outdoors and enjoy the flow of water. During the long-duration missions, astronauts/space tourists struggle with seeing the same people, performing routine tasks, and the space habitat becomes a place of likely rising conflicts. Not everyone can tolerate the isolation and loneliness encountered on long space flights, but a well-thought-out human-centered design can significantly relieve these issues.

Fuller thought alike. For Fuller,

". . . a room should not be fixed, should not create a static mood, but should lend itself to change so that its occupants may play upon it as they would upon a piano" (source?).

What interested him were the energetic events within the space limitation, which he called the "circumferential moment."

Space habitats—that are comparable to the Dymaxion House in affording diameters of 10 m or greater—pose a fascinating basis for comparison. In the case of using flexible shell space habitats (e.g. inflatable), the inner systems are stowed in a rocket payload and delivered to the final destination apart from a habitat. While the cost of transportation is a major factor in space exploration, taking as less space of fairing as possible enables bringing more supplies for a longer stay.

Return to the definition of synergy: "Synergy means behavior of whole systems unpredicted by the behavior of their parts taken separately." Is the Dymaxion House "synergetic?" With Fuller's design approach of interconnectivity and interdependency of elements from the first place, it does imply the multifunctionality of all of the design objects and perfect alignment of household items and structures. Similarly, from a subtractive design perspective that considers the entire habitat as the framework for an ecosystem, taking even one of the elements or subsystems away would break the super-system of the carefully designed and developed whole. The *unpredicted* behavior of a part can be perceived by looking at the element outside of the larger design context.

7. Conclusion

The Dymaxion House presents an imperfect but illuminating analogue to the design of a space habitat. Superficially, several commonalities jump out from this comparison. Both the Dymaxion House and a space habitat contained in a pressure vessel must adhere to a rigorous curvilinear geometry that does not allow casual additions violating that geometry. Both are eminently concerned with reducing mass and saving weight. Both depend—at the time of their creation—upon state of the art aeronautical or aerospace manufacturing techniques for advanced alloys. What is the most important commonality is the imperative to optimize each subsystem to serve its purpose, even though this .goal is often not accomplished, especially in space habitats.

Having recorded these similarities, there significant departures from this commonality. These departures include:

- the articulation and availability of the "free" volume;
- the accessibility of mechanical services and utilities,
- the ease of cleaning,
- the fraction of circulation areas and volumes in a ratio with total "habitable" volume,

- daylighting through windows, and
- natural gravity flow ventilation.

In a pressurized space habitat, the primary structure of the pressure vessel(s) is essentially identical to the pressure envelope and coterminous with it. However, in the Dymaxion House, the primary structure of the central mast is entirely separate from the spatial and volumetric enclosure. However, the secondary structural elements of the tension tie rods are closely integrated with the aluminum cladding of the roof and walls, creating together a quasi-tensegrity structure

Fuller's approach to mass-producing self-sustaining and lightweight homes, alike space habitation -- it to do more with less, to allow people to live lives they wanted.

The most significant determinant of the shape that is best suited for habitat from an engineering perspective is whatever best accommodates the internal pressure of the living volume and fits adequately into rockets. The cost is smaller to proceed with a minimum amount of mass and volume of the habitat structure, thus to reserve more funding to maximize the amount of mass, volume, complexity, and function of all the furniture and interior structures that are inside of a habitat. The authors believe that Fuller's influence is interplanetary in a way that his approach can be applied to all of the extreme environments that humans explore and settle on.

8. Acknowledgements

Marc Cohen would like to thank industrial designer Alan Lubow for introducing him to Bucky Fuller's work at a young and very impressionable age. Marc would also like to thank Zann Gill for introducing him to J. Baldwin, and to thank J. for invaluable insights into Bucky Fuller.

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