IMPEDIMENTS TO INTEGRATION: THE DIVERGENT INTENTIONS AND CONVERGENT EXPRESSIONS OF THE DYMAXION HOUSE AND DEMOUNTABLE SPACE STRUCTURAL DESIGNS

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INFLUENTIAL VOICES

During an intense and consolidated period of time in the 1940s, the architecture and construction industry underwent a massive paradigm shift. Postwar projects needed to have an elevated concern for creating large quantities of affordable, quality spaces with an inherent level of efficiency and affordability in their designs. Synergistic relationships between modern industrial production and overall construction methodologies were formed, new innovative products and processes that could improve building performance and constructability were invented, and eventually a new focus for the design industry emerged.

During this era, two very different projects were proposed which shared a similar manner of structural expression: The Dymaxion House by R. Buckminster Fuller (1927-45) and Eero Saarinen's Demountable Space proposal (1940-42, with Ralph Rapson). Both designers developed national reputations as technically proficient, innovative and creative designers, yet both were unique among their peers in their capacity to articulate the design logic of their structural systems as a primary generator of building form.

Both projects prioritized the minimization of on-site construction time, so they featured pre-assembled modular components, which could be erected with the assistance of the main structural system—a highly visible mast and cable suspension system.

Yet there were fundamental differences to which both designers pursued the efficiencies of structural form and technological integration in their designs—Fuller, being the more visionary, rigorous and uncompromising of the two. For quite different reasons, both projects failed to demonstrate the usefulness of integrating innovative structural solutions into future prefabricated building projects. This project will compare the fundamental problems of constructability and technical integration inherent in the designs of both projects.

Total Technology for a Total Population

> *"I didn't set out to design a house that hung from a pole…I started with the Universe as an organization of regenerative principles…I could have ended up with flying slippers."* -Buckminster Fuller[1]

In 1928, after being fired from a job in the construction industry, Fuller developed a philosophy of industrialization that essentially concluded with the belief that humankind could actively evolve by transforming our patterns of "making" to create more possible efficiencies by harnessing our available technology.[2] Fuller wasn't trained as an architect, but he immediately involved architectural explorations as part of his life's work. In his first explorations, he sought to apply his philosophical ideals to the creation of a series of objects and structures, including one of his first experiments, the 4D House. The project was later renamed the Dymaxion House by Marshall Fields department store advertising agents as a reflection of Fuller's often repeated words: dynamic, maximum, and ion.[3]

Fuller claimed that, "I could already see then that if everyone was to get high quality shelter, houses must be mass-produced industrially, in large quantities, like automobiles,"[4] so he set out a decades-long design experiment, creating an evolving set of related ideas and prototypes meant to explore the basic physical and psychological relationships between dwelling and technology. For the sake of clarity, the paper will focus on the conceptual intentions and the physical qualities of the initial, most complete version of the Dymaxion House.

The formal clarity of the Dymaxion House comes from its oft-quoted description as a "house on a pole." The design features a centrally located structural steel mast that held up a 1,700 square foot hexagonal-shaped floor plan "wheel" of living space that encircled the mast—this enclosed living space was held in place one story above the ground floor plane with the use of six high-carbon steel tension cables strategically located at the corner points of the hexagon along outside wall. These cables extend up above the living space, become visible in the open-air roof-top platform space, provide connections for the large hanging hexagonal metal roof cover, and ultimately secure themselves to the apex of the central mast which has necessarily protruded skyward one story above the roof platform. The cables continued down to the ground plane, crossed strategically into triangular patterns to provide both lateral bracing support from twisting and resistance to uplift. The lower portion of the mast was visible on the open ground floor plane and it provided three main, essential purposes: it served as an entrance to the elevator cab within the mast, it provided a location for all utility connections and vertical conveyance of mechanical systems, and finally, as a result of the house's ingenious consolidation of structural loads at this single component, it was the sole connection to a foundation. Fuller also envisioned that the mast would be used as the shipping container by which the remainder of the houses components would be transported to the site.

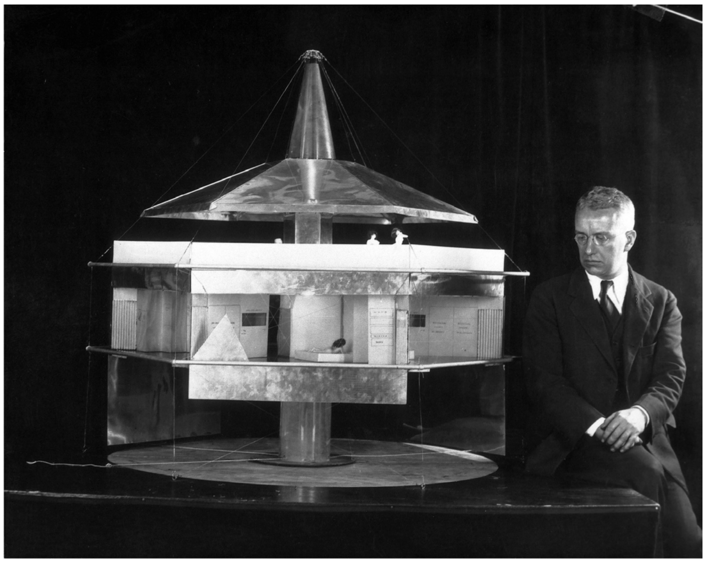

Figure 1. Fuller with model of Dymaxion House, 1927 (Courtesy, The Estate of R. Buckminster Fuller).

Throughout his career, Fuller insisted that the reduction of an object's weight be evaluated proportionally against its relative level of efficiency—a term he called ephemeralization.[5] For Fuller, a lightweight structure reflected an efficient combination of materials and forms created to effectively resist and resolve structural forces. However, to achieve a significant reduction in a structure's weight compared to conventional building systems required a complete rethinking of typical construction materials and methods. Fuller tried to achieve lightness with a two fold approach: first, he would control the type of stresses resisted within the structural members through formal configuration of the structural components, and secondly, he would, as needed, imagine and invent new material assemblies to take the place of conventionally heavy components.

For the Dymaxion House, Fuller's combined tensile and compressive elements together in an elegantly reductive manner. The compressed tower held up the tensile cables, which secured to two horizontal compression ring "hoops" at the roof and floors levels. Instead of using a typical floor framing system with members in bending, Fuller instead invented a series of pneumatic bladders (whose membrane was held in tension by air pressure) that could be sandwiched between two layers of horizontal wire mesh pulled tightly between the compression ring on the perimeter and the central mast. These strategies allowed Fuller to use the smallest, lightest, most efficient structural members. Fuller insisted that most of the house components would weigh less than 10 pounds each, light enough for one person to carry in one hand. As a result he calculated the final projected weight of the house to be only 6,000 pounds—around $1/50^{th}$ of the weight of a conventionally framed, smaller, single-family residence.

The logic of the entire project thus followed that if the components were mass-produced in large quantities AND if the entire assembly weighed less, it would cost less, and become easier to package, ship, and ultimately assemble. There was a direct relationship between the project's structural form and its inherent economic efficiency.

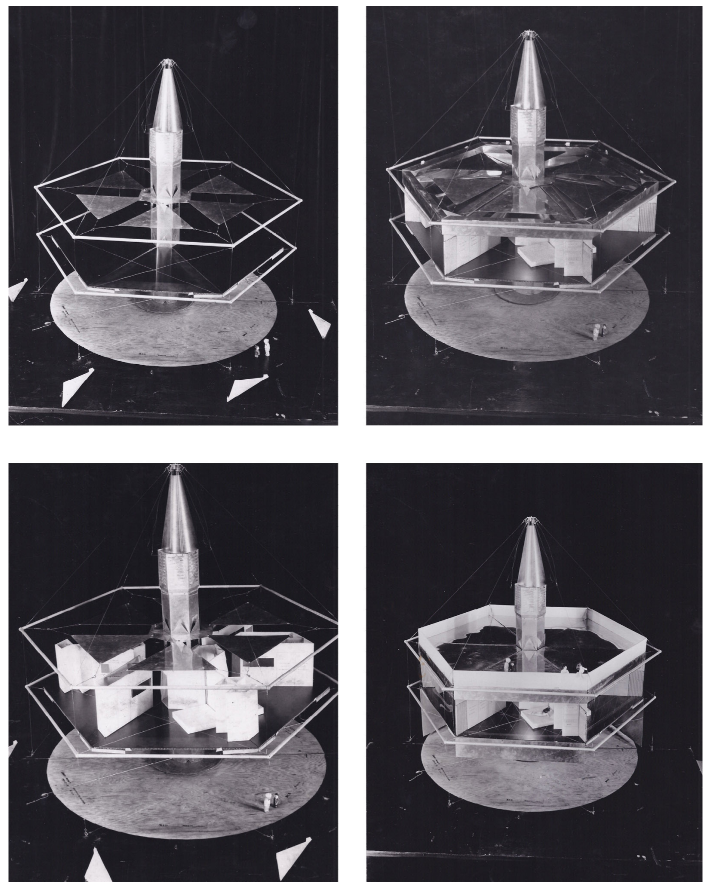

Figure 2. 4D Dymaxion House models showing erection sequence, 1927 (Courtesy, The Estate of R. Buckminster Fuller).

Fuller's design was filled with other visionary innovations related to the internal workings of a typical dwelling that were so advanced, that they were unable even to be prototyped as the industrial capabilities were not yet developed to fabricate the items. For example, all furniture was pneumatic, a triangular worm-drive elevator, an "atomizer bath" system which used only one quart of water, an automatic system to wash dry and store laundry, and relay switch-activated doors. Each item in the proposal was more revolutionary than evolutionary, and each piece was physically and conceptually so reliant on the others that substitutions and compromises didn't seem possible. When asked by a representative of the 1933 Chicago World's Fair how much it would cost to build a prototype for the fair, Fuller responded, "the basic cost is one hundred million dollars."[6] The house itself didn't cost that much—the real cost was in the necessary reconfiguring several manufacturing industries needed to make the Dymaxion House ultimately affordable.

Not surprisingly, even after receiving tremendous acclaim and a wide amount of publicity, no units of this proposal were ever built. Fuller was dismayed at the lack of attention and momentum that his ideas had. He thought, "a better construction system would, if industrially developed and demonstrated, thereby induce a spontaneous and simple acceptance," but instead he claimed to have found, "inertia, ignorance, and irrelevant ambitions,"[7] including a public rejection from the national American Institute of Architects (AIA) on his offer to turn over all patents for the project to the association, by stating that the association was "inherently opposed to any peas-in-a-pod reproducible designs.[8]

While Fuller claimed not to be disappointed by this general dismissal, stating he was satisfied because, "all of his models met his rigorous set of calculations and assessments," its lack of prototyping now can be seen as a profound lost potential to test certain characteristics that would have advanced the prefabrication industry. In particular, the innovations proposed for the structural system were well founded, relatively available, and buildable, yet because the project inextricably tied together all of the project's innovations as one completed project, the dismissal of one set of ideas perhaps unfairly caused the dismissal all ideas.

In 1941, after Fuller had authored a book called Nine Chains to the Moon (1938), he had moved on to other inventions, and was appointed head of mechanical engineering on the Board of Economic Warfare by the Secretary of the Navy; a position that allowed him to study world economic resources and to work in Washington, D.C. Soon after moving to Washington D.C., Fuller met a young architect from the Cranbrook Academy of Art named Ralph Rapson who couldn't wait to discuss architectural design with Fuller.[9]

Symbolic Reverence

> *"The principle of structure…is a potent and lasting principle, and I would never want to get very far away from it. The degree to which structure becomes expressive depends to a large extent on the problem. To express structure is not an end in itself; it is only when structure can contribute…to the other principles that it becomes important." Eero Saarinen, 1959.[10]*

Coincidentally, Rapson was in D.C. to meet with his collaborator and teacher, Eero Saarinen who had recently taken leave of his teaching position and practice at Cranbrook to work for the Office of Strategic Services (OSS). The purpose of the trip was for Rapson

Figure 3. Roof assembly (upper), on site ready to be installed (lower)

and Saarinen to discuss their design progress on a proposal for a hypothetical, pre-fabricated, domestic-defense related project they were working on for the United States Gypsum Company, called "Demountable Space."[11] Rapson never claimed that he and Fuller discussed the Demountable Space project during their social event or if the design changed as a result of this meeting, but when the final proposal was published later that year in a three-page spread in *Architectural Forum*, it was clear that the Demountable Space found clear inspiration for its structural system and overall image from the Dymaxion House mast and cable scheme.[12]

In 1940, when the project was initially commissioned, U.S. Gypsum's design goals called for the creative integration of their products into a wartime community center that could be quickly erected and demounted—a task that would require both creativity and technical expertise, so the selection of Saarinen made sense. Even at the early stages of his career, he had developed a reputation as an important emerging talent with extensive experience creating wartime architecture.[13] Saarinen sought to incorporate innovative products and processes in his practice, mostly by interacting directly with a diverse range of manufacturing and construction industries, so he was seen as more of a keen collaborator and innovative problem solver than a pure inventor like Fuller.

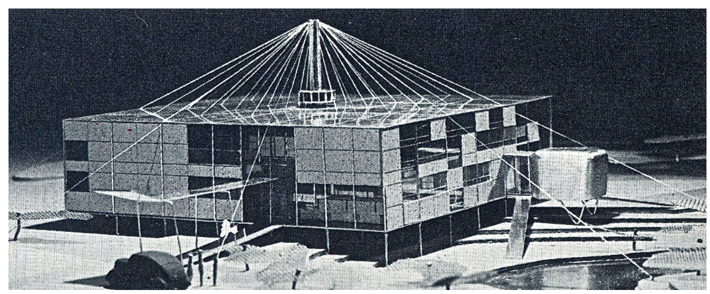

Figure 3. Demountable Space model photograph, from U.S. Gypsum's advertisement (Architectural Forum, March 1942).

The project's final publication featured explanatory text, plans, a detailed sectional perspective, model images, and clearly recognizable sketches by Rapson illustrating the proposals many innovative features. The design was, in its simplest terms, a large 5,000 square foot, 20' tall modular box with a central mast and cable system emerging from the center of the roof. The drawings and text described how a series of prefabricated floor, roof, and wall panels (made from U.S. Gypsum products) could be assembled on-site and erected in-place using the central mast as a crane. The elevations were shown as optional arrays of solid panels and operable windows, all set within a regularly repeating datum of vertical and horizontal lines. This box had certain pavilions and canopies extending from its main volume that housed the outbuildings, restrooms, and building entrances. The text described the project as a "social center for changing civilization in the postwar period" and correspondingly the floor plans showed a relatively column-free interior space so that a series of large community spaces (theater, gymnasium, activity rooms, etc.) might be arranged within the large interior volume without conflicting with the building's structure. Like Fuller's proposal, the central mast was shown as the sole means for the building's erection, it's primary means of support, and as the primary distributor for mechanical and electric services. The final sketch showed how the suspended structural system could be repeatedly employed to bi-axially extend the building size as needed.

The key symbolic and functional feature of the project, and the reason it is so often compared to the Dymaxion house, was the central mast and cable system. Saarinen's text describes the central importance of this feature by stating, "(a) system of suspended construction, like a circus tent, provides the most economical demountable space."[14] Yet more in-depth analysis of the project's specific material and structural choices reveals that this proposal clearly overstated its relative economic and functional efficacy—it wouldn't create an easier or faster deployment, it wouldn't be significantly lighter, and wouldn't significantly contribute to a more flexible interior space than other types of possible structural systems.

In general, suspended construction systems, particularly for projects of a relatively modest scale, would not typically be selected if rapid construction was a top priority unless the proposed roof membrane was light and flexible, like the circus tent mentioned in the proposal. However, quite unlike a circus tent, Saarinen's proposal called for the use of heavy, rigid, roof panels—this would significantly alter the ease of its deployment.

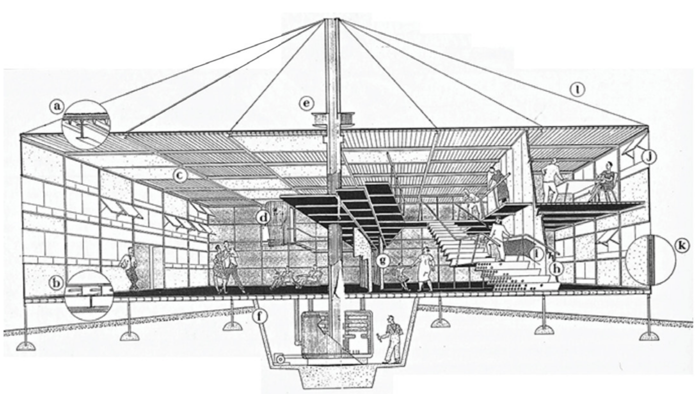

Figure 4. Demountable Space sectional rendering, from U.S. Gypsum's advertisement (Architectural Forum, March 1942).

Specifically, the priorities of rapid deployment and construction safety would necessitate that all sixteen separate 12' x 12' roof panels be adjoined on the ground first before being lifted into place (unlike some of the sketches Rapson included in the proposal showing only some panels lifted at once). Unfortunately doing so would create a massively heavy rigid 10-ton plane (each panel was estimated by Saarinen at 1,350 pounds). Lifting the roof into place, using only the single mast of the structural system, and keeping it stable from pitching and yawing during erection, would also be nearly impossible without other boom trucks, cranes, or temporary vertical structural supports. Alternatively, lifting each panel up separately would then require massive amounts of scaffolding to successfully adjoin each panel joint in place. Assuming the entire roof could be erected in place, keeping such a massive plane stable against wind uplift while the remaining building is constructed would be incredibly difficult and dangerous. These construction methods wouldn't contribute to a rapid deployment or demounting.

Another significant impediment towards proving its economic effectiveness is clearly its lack of lightness and inherent efficiency. In fact, besides the central mast and cable support for the roof, the remainder of the proposal used quite conventional structural components and materials. The central mast would ideally reduce the number of columns and allow for a less deep (although not necessarily lighter) structural roof members—by extension, this would seemingly also translate into the need for fewer foundations. However, unlike Fuller's proposal, which consolidated structural forces to only require one foundation, the Demountable space section shows additional footings at each panel intersection of the floor assembly. Because the floor was not held up by the roof structure like the Dymaxion House, this was obviously a reasonable structural proposal, but it was hardly an innovative solution that would contribute to a more economical or rapid erection of the overall building. Second, the roof and floor panels used traditional "section-active" framing members, such as beams—so these members are subjected to bending stresses, which requires more material to resolve the internal stresses.

Finally, and somewhat inexplicably for a wartime proposal, the entire structural system relied on the use of steel—a restricted material. This perhaps be explained partially by the timing of the proposal (it was commissioned in 1940 before America's involvement in the war) and/or by the statement in the proposal that this design was for "postwar," yet the central purpose of the project was to provide "demountable space," a goal clearly related to wartime domestic defense needs. One would not typically select a material like steel that was heavy, difficult to maneuver and time consuming to adjoin if rapid deployment and the ability to demount a structure were key priorities. Perhaps the easiest explanation may be that the project's commissioner, U.S. Gypsum, wanted to have their featured products appropriately associated with commercial construction practices that typically involved steel construction.

The need to create relatively column-free flexible space within the building was certainly understandable, as was the potential to employ this same system in a repetitive manner to allow for expansion. However, other structural arrangements of suspended systems, such as a one-way, cable-stayed system with columns at the perimeter, would have been easier to construct and would have used a comparable amount of materials. In fact, in 1942, architectural journals were filled with different proposals for innovative, economically feasible and efficient construction systems: Quonset huts, advanced laminated wood assemblies, and pneumatic membrane systems[15]—coincidentally some of these proposals were even published under the heading of "Demountable" spaces.[16]

Simply put, the proposal borrowed a highly memorable symbolic element from Fuller, but didn't resolve with any certainty many of the other important associated structural and assembly issues related to its selection. Not surprisingly, like Fuller, the proposal had no prototypes ever constructed and the structural scheme exerted little influence in the postwar pre-fabricated design industry.

Dismissal and Deliverance

> *"Dymaxion means, doing the most with the least."*
> - Buckminster Fuller[17]
>
> *"I want always to search out the new possibilities in new materials of our time and to give them their proper place in architectural design... basic things whose possibilities in architecture have not yet been fully fathomed."* -Eero Saarinen[18]

In the years following this proposal, both Rapson and Saarinen gained significant prominence in the field of pre-fabricated architecture. Saarinen (with Oliver Lundquist) won the prestigious "Design for Postwar Living" competition in 1943 sponsored by *Arts and Architecture* journal, and eventually designed the Case Study houses #8 and #9 for the same magazine.[19] Although later in his career Saarinen was celebrated for his use of innovative and expressive structural systems, these experiments were notably absent from his proposals for pre-fabricated buildings.

While Saarinen was winning accolades for his work, Fuller was finally given an opportunity to build a version of his Dymaxion House—albeit a version that was dramatically compromised from his original vision. In this iteration, more commonly known as the Wichita House, Fuller kept the general idea of a central mast and cable system but hid them from view by lowering the house to just above ground level, eliminating the upper platform and covering the tower with a predominantly expressed metal wind foil. He modified the arrangement, material selection, deployment methods, and overall expression in such significant ways that the house was hardly recognizable as an extension of the original ideas. Although nearly 3,500 orders were received, as a result of certain business problems, only two houses were built and only one remains in existence today[20].

The Dymaxion House, as originally designed, presented a vision for a highly integrated, technologically innovative building made from pre-fabricated materials developed by advanced manufacturing techniques. These materials were efficiently packaged, shipped, and ultimately assembled on-site rapidly. The building was light, efficient, and livable, exactly the type of project that should have been widely influential to an emerging pre-fabricated design industry. Yet because the original design components weren't able to be prototyped, tested, or modified, most of the proposals were never integrated into projects created by other designers later. Eventually, when attempts were made to reproduce the structural scheme for the Demountable Space, significant compromises were made to the original proposal including modifications of the overall scale, scope and configuration of components. Saarinen's proposal could have been reproduced, but there was no clear economic or manufacturing advantage in doing so.

This comparison reveals trends in their work that became more fully evidenced later in their respective careers. Even though both men were actively engaged in integrating a diverse set of advanced technologies into their work, Fuller produced the more prescriptive, uncompromising structures that resulted from the thoroughly developed myriad of complex inter-related technical solutions. Saarinen, however, usually favored flexibility of structural expression and often postponed the thorough examination of technical restrictions until late in the project's development.

Ultimately the comparison of the proposals should serve as both a warning and motivation for the integration of innovative structural solutions into the pre-fabrication building forms. The structure *can* be used express a project's inherent efficiencies, as long as it enhances the building's performance and not only its image.

ENDNOTES

1. Robert W. Marks, *The Dymaxion World of Buckminster Fuller,* (Carbondale and Edwardsville: Southern Illinois Press, 1960), 7.
2. Marks, *The Dymaxion World of Buckminster Fuller, 9.*
3. R. Buckminster Fuller, *Autobiographical Monologue/Scenario*, ed. Robert Snyder (New York: St. Martin's Press, 1980), 54.
4. Fuller, *Autobiographical Monologue/Scenario*, 55.
5. Federico Neder, *Fuller Houses, R. Buckminster Fuller's Dymaxion Dwelling and other Domestic Adventures,* trans. Elsa Lam, *(Lars Muller),* 115.
6. Marks, *The Dymaxion World of Buckminster Fuller,* 25.
7. Marks, *The Dymaxion World of Buckminster Fuller* 17.
8. Fuller, *Autobiographical Monologue/Scenario*, 57.
9. Jane King Hession, Rip Rapson, and Bruce N. Wright, *Ralph Rapson: Sixty Years of Modern Design*, (Afton: Afton Historical Society Press, 1999), 30.
10. Eeva-Liisa Pelkonen and Donald Albrecht, eds., *Eero Saarinen: Shaping the Future, (New Haven and London: Yale University Press, 2006), 350.*
11. Jayne Merkel, *Eero Saarinen, (London: Phaidon Press Limited, 2005), 56*
12. Hession, Rapson, Wright, *Ralph Rapson: Sixty Years of Modern Design*, 31.
13. Pelkonen and Albrecht, *Eero Saarinen: Shaping the Future,* 328.
14. "Demountable Space" Advertisement, *Architectural Forum*, March 1942, 50-53.
15. Herbert Stevens, "Air-Supported Roofs for Factories," *Architectural Record*, December 1942.
16. "Demountable School", *Architectural Record*, May 1942, 68.
17. Fuller, *Autobiographical Monologue/Scenario, 54.*
18. Pelkonen and Albrecht, *Eero Saarinen: Shaping the Future, 352.*
19. Pelkonen and Albrecht, *Eero Saarinen: Shaping the Future,* 142.
20. Neder, *Fuller Houses, R. Buckminster Fuller's Dymaxion Dwelling and other Domestic Adventures, 171.*