

Experiments in DIY Spaceframes

Version 5.0

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Preface

This essay describes my experiments in DIY Spaceframe Platform fabrication. It lies at the intersection of my work in 3D Geometric Form Study (see <https://omnigarten.org>) and my investigation into house construction innovations like WikiHouse (see <https://wikihousepdx.com>).

Introduction

Given that established neighborhoods and commercial areas have utilities and transportation infrastructure in place, and are near stores, services, schools, and parks, etc., we can all recognize the enormous social and economic value of infilling within the existing urban gridwork. It is thus imperative to consider and act upon all reasonable infill strategies.

While the WikiHouse construction concept is about affordable DIY housing **structures**, to create truly affordable housing, we also need **affordable places to build on**. DIY Spaceframe platforms may help us achieve this by enabling us to create building surfaces in places within established urban areas where conventional foundations are not economically or logistically feasible. It is about providing more possibilities for where we can erect small houses, like WikiHouse.

A spaceframe can be generally characterized as a set of struts (commonly steel tubes) that are bolted or welded at their endpoints to a common connection joint to create a three-dimensional geometric network of nodes in patterns of triangles and squares. In pure geometric terms, a spaceframe is an Octahedral-Tetrahedral Lattice as shown in Figure 1.

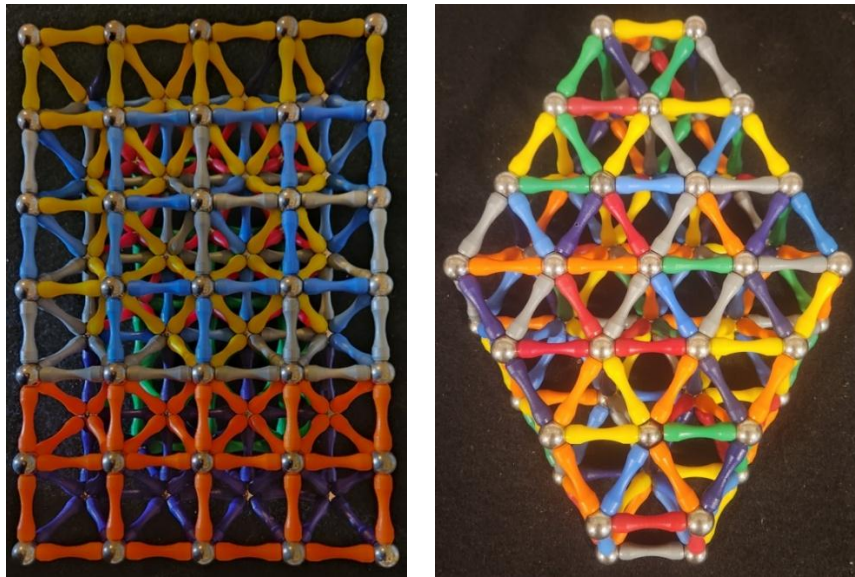


Figure 1: Two Views of the Octahedral-Tetrahedral Lattice

Buckminster Fuller called them 'OctTet Trusses' and used them in building large Geodesic Domes. There are two cleavage planes within the Octet. The Octet on the left is cleaved along its plane of Squares; on the right it is cleaved along its plane of Triangles. Figure 1 shows two aspects of the same structure. Both planar aspects can be used for building structures.

As a force diagram, the Octet is a perfect equilibrium of 'tension' and 'compression' members. Using the Octet in Figure 2 as an example, the struts of the **Square** plane (chord) are tension members, the **Diagonal** struts that inter-connect the parallel square planes are compression members. It's a fully triangulated structure. A load exerted on the plane at any given node is equally distributed to all other nodes to share giving the overall structure exceptionally high load bearing capacity and lateral strength. With large spanning capacity, a spaceframe requires fewer touch points to earth compared to other foundation types like wood post and beam. In Figure 2 we see that only corner supports are needed, no interior support, for a relatively large platform area.

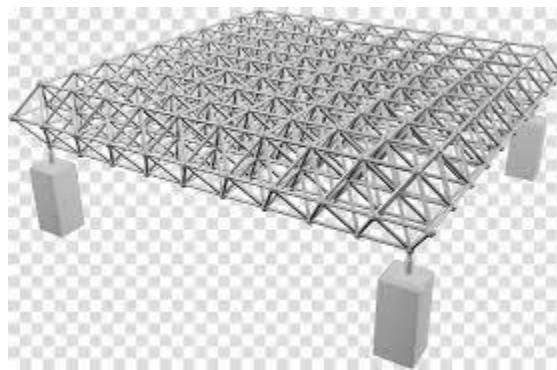


Figure 2: Example Spaceframe requiring only corner posts.

With Octets a variety of geometric shapes and sizes can be built. Architects of large (dramatic) structures design spaceframe geometries that are then manufactured by one of just a few large companies in this field. This operating model is largely out-of-reach, cost-wise and logistics-wise, for the DIY WikiHouse builder. Our focus here is on small-scale affordable DIY rectangular spaceframe platforms that, like WikiHouse, have sub-sections fabricated in a small shop, then trucked to the building site where they are assembled into the final platform by a small workgroup. Sub-sections are meant to be hand carried or lifted into place with a small, rented boom rig, then stitched together to create the final platform at the building site. They are not intended to be assembled strut-by-strut at the building site.

A Little History

Rankine and Maxwell:

"In the mid-19th century British researchers such as Thompson, Tait, Jennings and Airy, and particularly, Rankine and Maxwell made important contributions to engineering mechanics and structural engineering. In 1864 Scottish scientist and engineer William Rankine published "Principle of the Equilibrium of Polyhedral Frames". The paper consisted of only three paragraphs and four sentences but it inspired James Clerk Maxwell who soon afterwards published "On Reciprocal Figures and Diagrams of Forces."

Maxwell's remarkable paper led to two-dimensional (2D) graphic statics and major contributions to graph theory".¹

Alexander Graham Bell was one of the earliest pioneers to experiment with (what he called) 'Tetrahedral Spaceframes'. Bell was primarily focused on creating structures to support human flight, so he was looking for a lightweight form with high strength-to-span capacity. The 'Bell Kite' and Cygnet structures were spaceframe structures that he experimented with in the early 20th century.

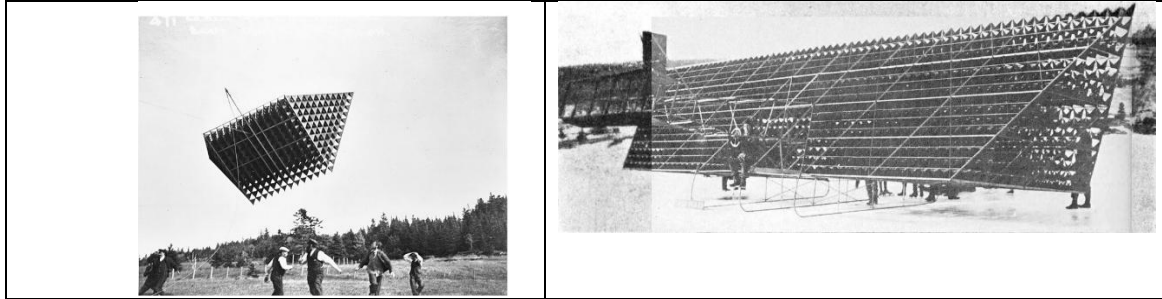


Figure 3: The Bell Kite and the Cygnet flying machine.

Buckminster Fuller designed and built a number of Geodesic Domes, but his first practical application of the Octet Truss was the dome atop the Ford Rotunda in 1953. We can see that he used Triangular Octets to create the dome facets.

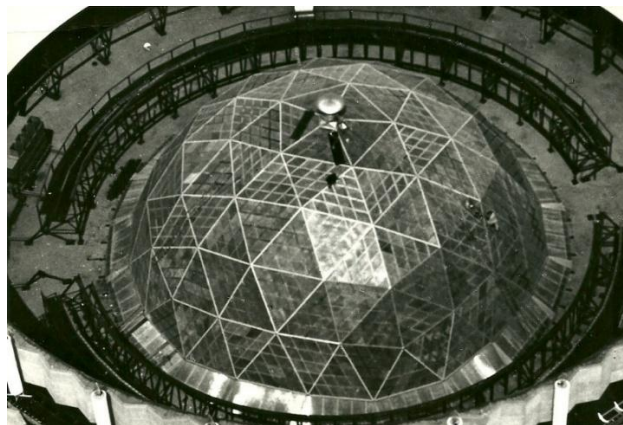


Figure 4: Ford Rotunda Dome

¹From the forward by Dr. William F. Baker for the book "Polyhedral Graphical Statics" by Masoud Akbarzadeh

Konrad Wachsmann designed and built spaceframes throughout the mid-20th century. He is noted for his “Building System” and his proposal for a never-built large aircraft hangar for the US Air Force.

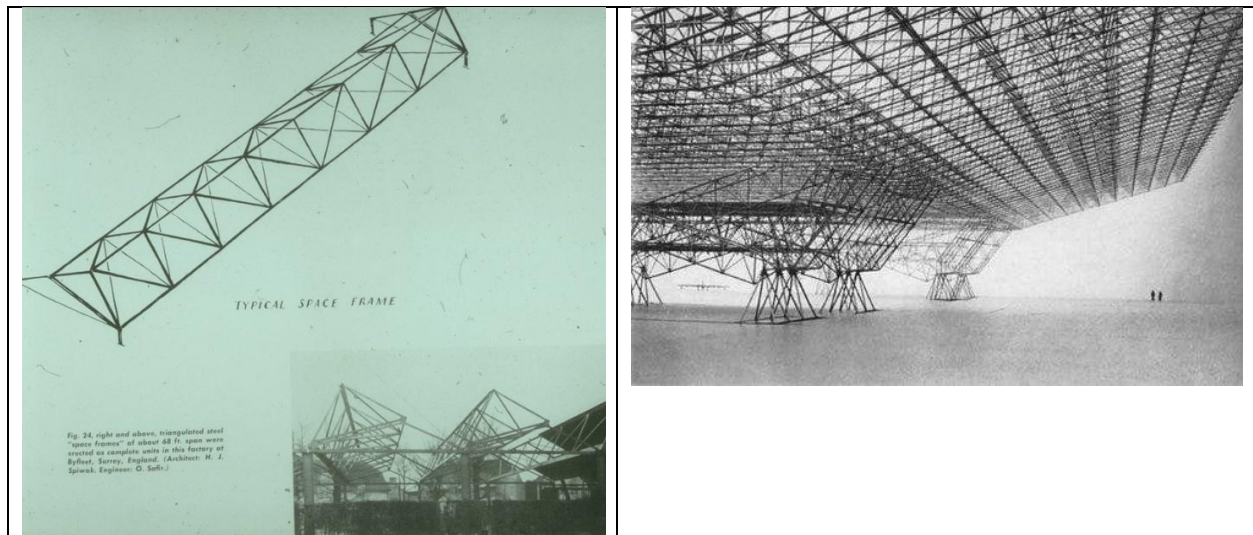


Figure 5: Wachsmann Building System on left. Prototype model of a US Air Force hanger on right.

A more recent spaceframe theorist and architect is **Peter Pearce**. Pearce is notable for designing the ‘Habitat’ building of the BioSphere II complex in Arizona in the early 1990’s. It was large, strong, and notably, the glass glazing system was airtight.

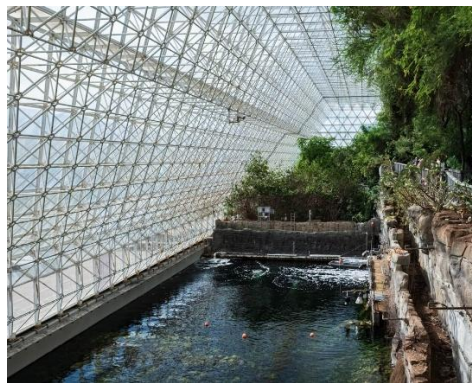


Figure 5: BioSphere 2 Habitat Building

Peter Pearce’s HolosHouse, (aka EcoHouse, [HólosHouse - Peter Jon Pearce Design](#)) was designed in the early 21st century. While the Pearce HolosHouse utilizes a spaceframe for everything, e.g. floors, vertical walls and roofs ...

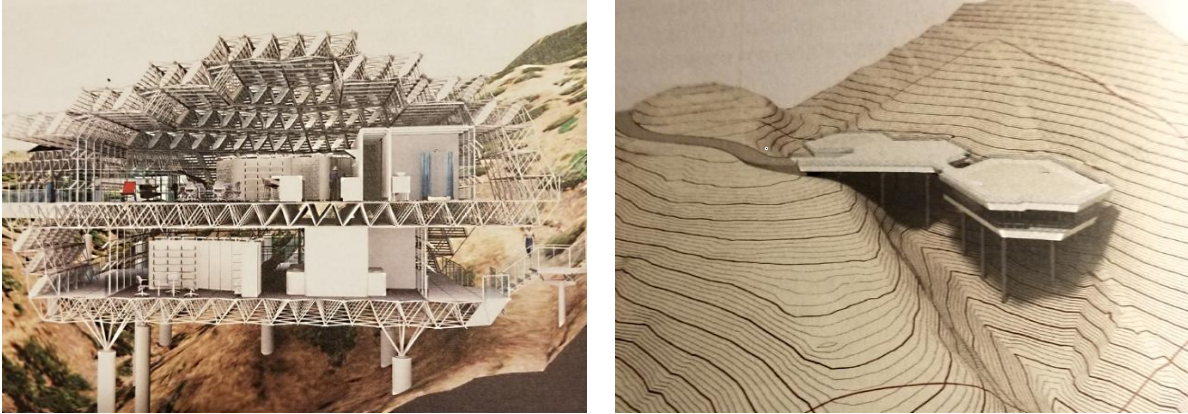


Figure 6: Side view of Pearce HolosHouse. HolosHouse Spaceframe Platforms.

... it is the floor platforms, contoured to the hilly landscape by concrete columns, that have inspired the idea of a low-cost DIY spaceframe platform.

To get a sense of scale, each of the three platforms shown in Figure 6 is approximately 1360 sqft. That such a large building area can be supported by a relatively small number of support columns, is due to the load bearing capacity of the Octet Spaceframe geometry. There is also the advantage of being able to lift into place manageable sub-sections to assemble the final form. Peter sums up the spaceframe value proposition like this:

*“The building shape is designed for maximum structural advantage. The shape is guided by the concept of ‘**strength of geometry**’. In this concept, the dominant parameter for structural engineering is building shape, not strength of materials.”*

The Pearce Holoshouse hints at the **versatility** of spaceframes. When purposed for smaller buildings in established urban areas (i.e., not necessarily the rugged mountain landscape like the Pearce Holoshouse), I believe this versatility can enable **radical urban infill**.

My Experiments with DIY Spaceframe Platforms

Experimentation started by modeling and studying a geometrically pure Octahedral-Tetrahedral Lattice where every strut is the same length, as shown above in Figure 1. The struts of the modeling tool used in Figure 1 have strong magnets at their ends. They magnetically affix to the steel-ball node piece. This is not a recipe for actual platforms that can bear weight. The secret of applying the Octet to practical, load-bearing, purposes lie in the design of the Node. Commercial spaceframe manufacturers have proprietary node designs created with sophisticated software to calculate strut-to-node angles and manufactured with sophisticated machinery.

In my experiments I went through several designs of node pieces. My **initial criteria** were:

- 1) The nodes and struts can be fabricated in a small shop with common, inexpensive tools. No specialized equipment or software. Simple fabrication steps.
- 2) The nodes should allow for a support post to slide through the vertically aligned nodes of the top and bottom chords (plane of squares) to varying lengths so that the spaceframe could be height adjusted to meet the ground below it at whatever depth the contour of the land required for the

platform to be level. As such, initial experiments were about developing a node that was hollow (unlike most commercial nodes that are solid.)

- 3) All struts to be the same length to keep it simple.

My first node design was a sheet metal collar intended to allow the widely available pressure-treated "4x4" (3.5"x3.5") wood post to slide through. That design is shown in Figure 7.

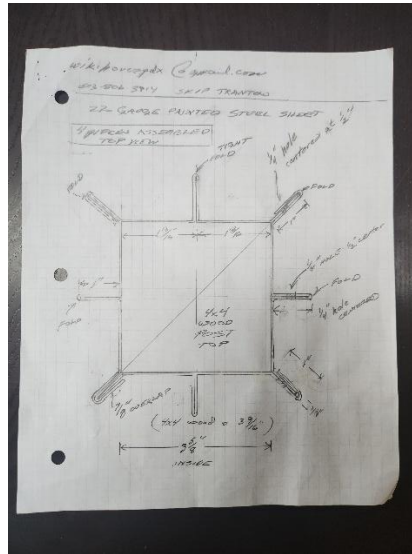


Figure 7: Design and dimensions of sheet metal node collar.

Figure 8 shows early sheet metal node prototypes intended for wood node plugs and support posts.

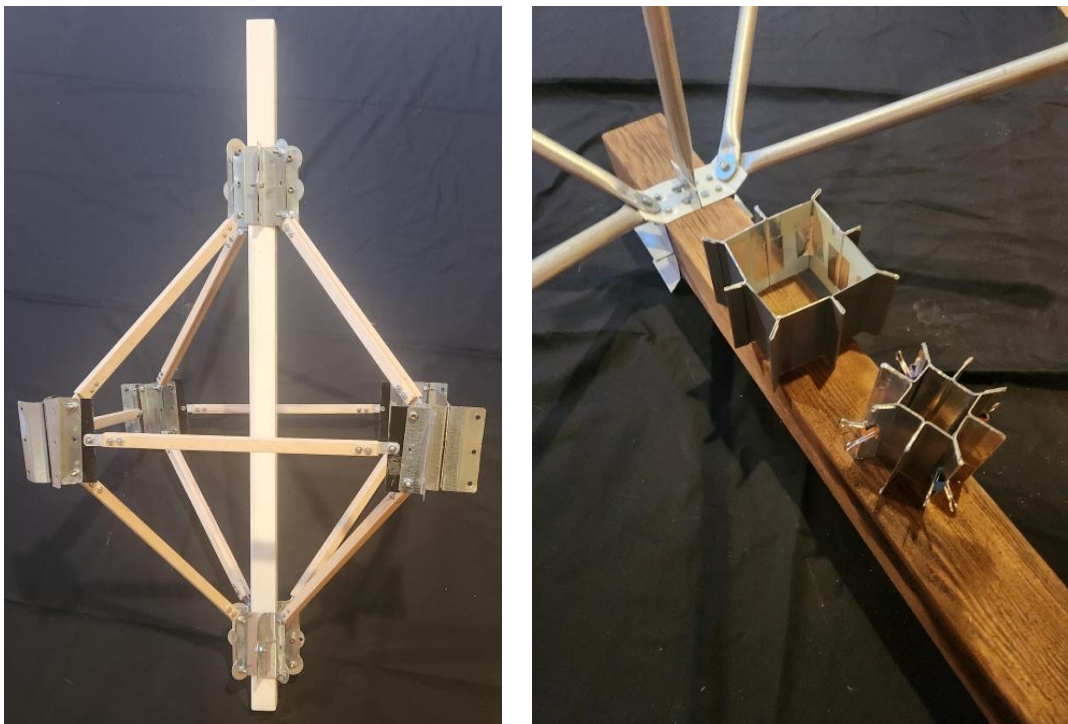


Figure 8: Sheet metal nodes for a 2"x2" (1 5/8" square) post, and for a 4"x4" (3 1/2" square) post.

The struts of the Square plane enter the node laterally. For all struts to be the same length the Diagonal struts needed to enter higher up on the node piece so that all node lines intersect at the center of the hollow area of the node. To achieve this the collar had to be quite wide as observed on the two empty collars on the right side of Figure 8.

After this experiment it was clear that the sheet metal collar node with wood inserts was **not practical**:

- It took too many steps to bend and form the sheet metal collars. (It could be feasible to extrude the shape as a single long piece then slice off the collars. But this would add expense.)
- Using a single strut length, the node's 'attachment wings' had to be quite large to accommodate the different angles that the Square and Diagonal struts required to meet the node piece.
- Using a uniform strut length produced a two-chord spaceframe that was unnecessarily deep (thick). It needed to be thinner to be practical.

The idea of a node that allows the assembler to slide a wood post through it to level up and support the platform is appealing. Perhaps an extruded aluminum collar would work, but for now, **this design was eliminated**.

However, this experiment hinted at the next step, which was to determine if two different strut lengths could be used to make the platform thinner, and if the struts could all be attached on the same plane of the node piece so that the node could be thinner. If so, then a different node design would be possible. This required building a small-scale model shown in Figure 9. The top plane-of-squares (black) was our unit length (23 cm), the inter-chord diagonal struts (red) were shorter at 18cm. A ratio of approximately 0.8. It worked!

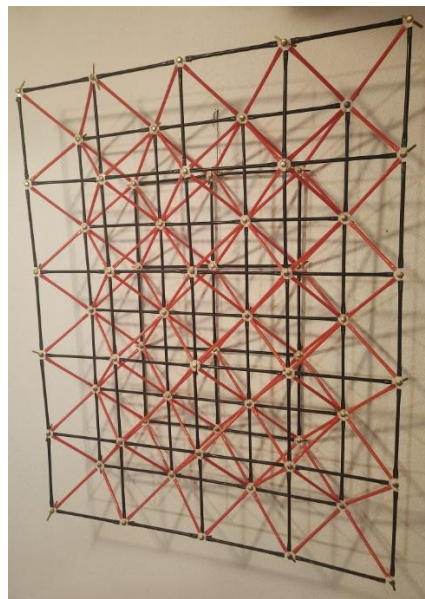


Figure 9: Model of 3-chord Octet using two different strut lengths.

This experiment informed the next node design which was a flat metal ring with eight small ($\frac{5}{16}$ ") holes in the ring perimeter area and a single 1" threaded hole at center. To experiment, commercial cast iron flanges, $\frac{1}{4}$ " thick, were used to create what I call the 'ring node'.

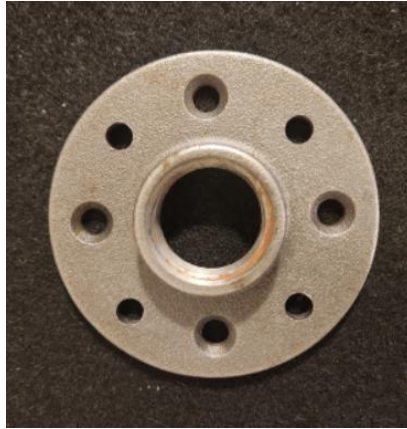


Figure 10: Ring Node

To this node were bolted steel struts made from $\frac{3}{4}$ " EMT (Electrical Metal Tubing) conduit pipe. Two strut lengths were used: For the Square chord: 22.75", for Diagonals: 17.5", an approximate 0.8 ratio. The ends of the Diagonal struts were angled 30 degrees. The struts had flattened ends with $\frac{5}{16}$ " holes drilled $\frac{1}{2}$ " from the end. $1" \times \frac{1}{4}"$ bolts were used to fix the struts to the node ring.

Figure 11 shows a 6'x8' frame that uses the Ring Node. To demonstrate the capability of this design to adjust the corner heights to make it easy to level the platform on uneven ground, threaded $\frac{3}{4}"$ rods pass through the upper and lower ring nodes of two of the corner octahedrons. These are secured with nuts that were adjusted to level the entire platform while straddling two levels of deck. Attaching the posts to the vertically aligned top and bottom nodes of the corner Octahedrons provided lateral stability to the entire frame.



Figure 11: Spaceframe using the Ring Node with level adjustable corner posts.

Figure 12 is a closeup of one node that is fully populated with struts.



Figure 12: Ring Node closeup.

I built two configurations, 6'x8' and 4'x12'. I did no rigorous, scientific load testing on these Ring Node spaceframes, but I found them to be rigid and relatively light. They both held up to a 200lb load at their center without noticeable deflection.

What was the verdict on the Ring Node design? **It was not a practical design - too much work to assemble.** There were too many bolts to fasten in place – 8 per node. A DIY spaceframe needs to be easy and fast to assemble. However, lessons were learned. **“Progress belongs to the experimenters!”**, so onward we go.

The Wood-Steel Hybrid Design

At this point I observed and learned that I could treat the struts of the Square Chord as independent of the Diagonal Struts. The strut patterning system works **as long as** you make the strut length and attachment pattern uniform for all the horizontal Square Chord struts, and uniform for all the Diagonal struts. With that in mind, I viewed the spaceframe platforms simply as two Square Grids. The Square Grids could be made from a crisscross of wood boards bolted together at their intersections to form a node point. The Diagonals (all equal length) simply travel from a node on the top Square Grid to a node on the bottom Square Grid. In this design, at each node there are two perpendicularly stacked wood boards and 4 metal struts. The node point was essentially a 5/16" hole with a sufficiently long 1/4" bolt binding together the 2 intersecting wood boards and the 4 metal Diagonal strut ends.

Figures 13-15 show the sequence of creating the **“Hybrid Wood-Steel”** spaceframe. For this experiment I used 1.5"x0.75"x8' cedar slats (colloquially, 8-foot 1x2's). I measured out equal hole spacing of 22.75" on all boards, then drilled 5/16" holes in the center of the boards, per Figure 13.



Figure 13: Wood boards with holes drilled. These will crisscross to make the square chords.

The boards were roughly laid out in the form of the square grid. Then the Diagonal struts are bolted in at the node point, i.e., the intersection of the wood boards. See Figure 14.



Figure 14: Rough Layout, then bolt on the Diagonal Struts.

Figure 15 shows the assembled 8'x8' 2-chord spaceframe.



Figure 15a: Assembled 8'x8' Wood-Steel spaceframe sub-section.



Figure 15b: Top-view of 8'x8' Wood-Steel spaceframe sub-section.

Notice the over-run of the boards in the X and Y directions. These make it possible to splice two sections together at the building site. Simply bolt on a 'splice board' to secure two grid boards together and then connect Diagonal struts to stitch the two sub-sections together into a larger spaceframe. This process can be repeated, basically, ad infinitum.

What was the verdict on the Hybrid Wood-Steel design? **It worked great! It's a promising candidate for further study and development.** It meets the most important elements of my criteria for a practical DIY spaceframe:

- It's easy to build the components and easy to assemble them into a spaceframe subsection. (In fact, **surprisingly easy!**)
- Sub-sections can be sized so it is manageable for one or two people to handle them. For example, boards in one direction could be 12' and in the other direction 10', yielding a 10'x12' rectangle that is about 16" deep. This size would be light enough for two people to carry and load sections upright onto a truck with the long edge down on the bed. At the building site it would be manageable to carry and anchor the sub-section onto support posts.
- The Hybrid Wood-Metal design meets the '**single strut**' criterion as only the Diagonal steel struts need to be fabricated. This was easy to do: Simply cut $\frac{3}{4}$ " EMT pipe to equal lengths. Flatten the ends in a vice. Drill a hole in each end. Bend ends to the desired angle. The angle is dependent on the length of the squares and the desired depth of the spaceframe. Here it was 30 degrees. It doesn't have to be too exact; it will pull in to correct orientation when the node bolts are tightened.

(Note that it may be feasible to fabricate the compression struts as a 'strut-group' by bending a zigzag (corrugation) pattern of angled struts into a single long tube, instead of fabricating individual cut struts. For further investigation.)

- It was light and strong. While I did not conduct a scientific load analysis, I put a load of 320lbs on the center of the spaceframe in Figure 15 and there was no discernible deflection. It was also light enough that I could easily carry this spaceframe around.
- I think the ideal wood board would be about 3.0"x1.0" in profile. Thick enough for adequate tension strength without being too heavy. The wood rails also serve as a substrate to fasten wood or metal panels to the platform.
- Lastly, it can be built in a small shop with common hand tools. Figure 16 shows the tools and base components used in building these experimental spaceframes.

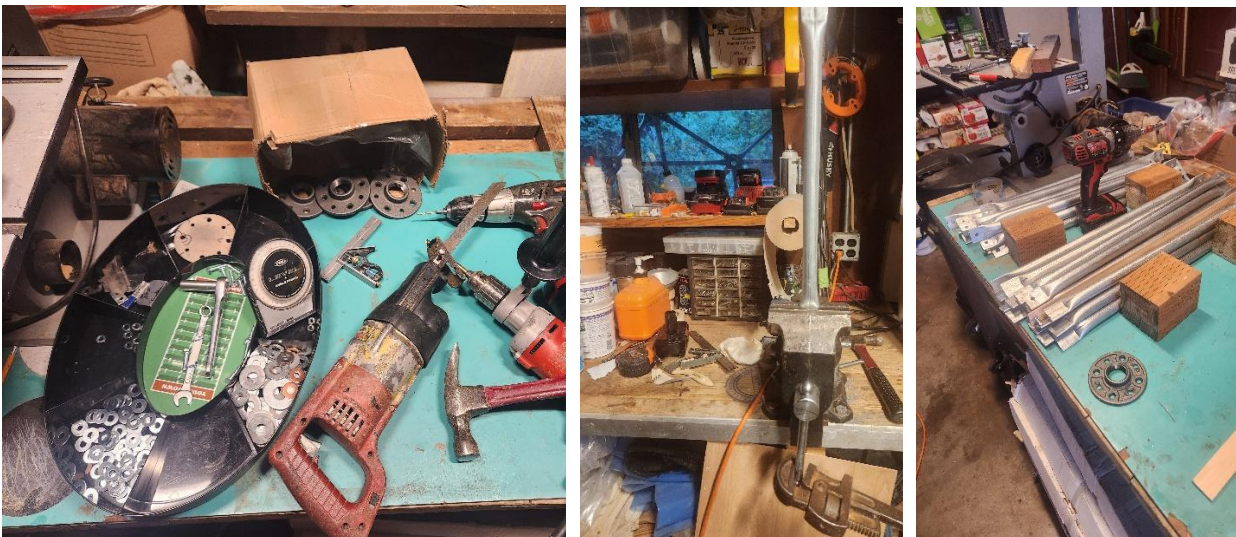


Figure 16: DIY spaceframe components and tools in a small workshop.

While the design of the Hybrid Node does not allow a support post to slide through it to ground, it is still very easy to install the support posts. In Figure 17, a mounting bracket is affixed to the upper node bolt on each corner (easy to do), then 4 more Diagonal struts are attached downward to secure them to the wood post. (Shown is a 4"x4 post.) This secures the platform vertically and also gives the platform lateral stability.

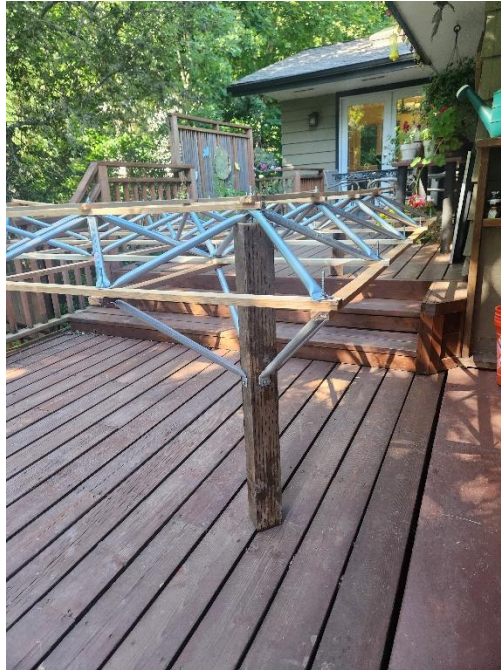


Figure 17: A stabilizing corner post.

Summation

Spaceframe pioneers have set the stage for applying spaceframe technology to housing. Yet most architects designing with spaceframes today generally focus on large structures. The proposition of the DIY spaceframe platform is to enable average people to build small houses or ADU's in urban areas where it is unfeasible to build with conventional construction methods. **Flat and level lots are expensive!** So, the idea here is to innovate and find ways to make it feasible to build on challenging (and less expensive) terrain and odd lot geometries.

Conventional foundations are expensive! In conventional buildings a load-bearing concrete foundation generally corresponds to the perimeter of the house and requires many interior supports. Excavation is required. Because of the high spanning and high load-bearing capabilities of an Octet spaceframe, support-to-ground can be concentrated onto a comparatively small number of columns, such as the corners. Ground contact may simply be a wood post on a concrete pad, or an augured-and-poured reinforced concrete column, or a steel post attached to ground screws, etc. Spaceframe platforms, requiring fewer touchpoints to ground, can make it economically feasible to create buildable space for housing in the urban gridwork where conventional construction methods cannot.

Through the lens of **agile and versatile house construction technologies** like WikiHouse and Spaceframes, we can 're-see' the urban landscape and realize that there are many spaces where people can self-build durable, aesthetic, affordable, permanent living units. **Radical infill!**

Key Values of Spaceframe Platforms:

- Excavation and foundation work minimized. Environmental impact and remediation cost minimized.
- Platform sub-sections can be prefabricated in a small-shop and trucked to the site for assembly thereby speeding up overall assembly of platforms. Multiple sub-sections can be placed on a flatbed truck.
- Fabrication in the shop and assembly of sub-sections at the building site is a repetitive and regular process. Simple training requirements for fabricators and assemblers.
- Components can be handled by a human worker minimizing the need for heavy lifting equipment. In cases where the landscape is steep and craggy it may require the use of a rented mobile boom to hoist and lower the platforms onto support columns. By contrast, post-and-beam wood structures must be assembled piece by piece – much harder.
- With plenty of space under and within the spaceframe platform, hook-up of electrical, plumbing and data utilities is easy.
- Weather-resilient, easy to maintain.
- Standardized, off-the-shelf kit of parts is possible.
- The stability and load-bearing capability of spaceframe trusses will likely meet city building codes and requirements. High-wind and earth-quake resilience.
- High flexibility to shape the platform to the geometry of the building site.
- As well as floor substrates, spaceframe platforms could also be used for roofs. Perhaps even walls.

Use Cases

- Span over hilly, pitched craggy land. Minimize excavation of land.
- Span over areas prone to occasional flooding.
- Brownfields, where few touchpoints to ground is desirable.
- Create indoor residences clusters within repurposed big box stores.
- Create house platforms on rooftops.
- ... and more.

In Closing

It must be restated that the above examples of DIY spaceframes are **experimental**. No formal load or stress testing has been done yet to determine if they would meet building standards. I believe they would. In the general sense these experiments point to a tool that small-scale DIYer builders can **innovate** with to build houses and shelters in areas and situations where conventional building methods are not feasible.