The Art of Tensegrity

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The Art of Tensegrity

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When Professor Motro invited me to contribute something for a special tensegrity issue of the Journal I was not sure what I would be able to write that might interest architects and engineers. As an artist I work directly from small scale models, quite different from the way other professions analyze tensegrity structures mathematically. My large works are required only to stand up by themselves and survive out of doors which they have done extremely well. “Easy Landing” on Baltimore Maryland’s Inner Harbor (Fig. 1) and “Free Ride Home” at Storm King Art Center have stood without need of repair for more than thirty-five years. Many more of my sculptures can be seen at: www.kennethsnelson.net

Because so many papers have been written about tensegrity’s performance and its proposed uses what I can add is the history of early discoveries; to relate some of what I learned for the first time over a half-a-century ago.

I want to be clear that I am writing about endoskeletal floating-compression structures not hybrids that include bicycle wheels, spider webs and WWI aircraft construction. A Google “tensegrity” search turns up nearly a half-million entries, many of which have nothing to do with discontinuous compression, continuous tension, structures.

The tensegrity story is likely to begin with the question who discovered what and when. In 1996, Volume 11 Nos. 1 & 2 of this Journal, the different views of Buckminster Fuller, David George Emmerich and Kenneth Snelson were thoroughly debated. I told of Mr. Fuller’s 1959 New York Museum of Modern Art exhibition when he finally credited me for discovering the tensegrity principle.

That local public acknowledgment offered me the freedom to go back to where I had begun and to explore whatever might still be left to discover about tensegrity. Mr. Fuller had always concentrated on spheres based on the geometry of his geodesic dome. His audiences saw models and pictures of the spheres as well as his “mast” adapted from my original X-Piece. Though my 1948 plywood and monofil sculpture (Fig 2) had given birth to “tensegrity”, Mr. Fuller chose not to describe it in his lectures or in his writing. Most remarkably, none of his students in schools where he taught had discovered it on their

Figure 1. EasyLanding

Figure 2. WoodX-Column1948

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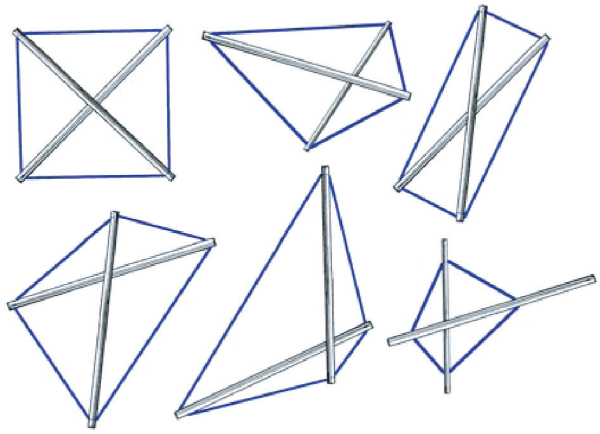


Figure 3. Kites variations

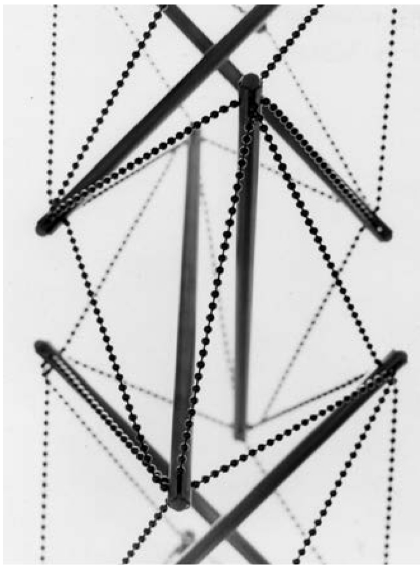


Figure 4. BeadChainTower

own. As a result the tensegrity X-module was unknown to anyone but Bucky and me.

So, in the Fall of 1959 I began constructing study models to explore ways of extending the conventional kite frame, the proto-tensegrity structure — a two-strut figure held together by a girth of string. It is generally disallowed as tensegrity because its sticks touch one another. While this is a fair distinction, the kite frame is a sturdy, prestressed, triangulated, endoskeletal structure whose parallelogram shape is endlessly adjustable. It is also a space-filling structure that can be repeated indefinitely by adding kite-frames module after module in all directions.

My studio was a small sixth-floor-walk-up apartment in a tenement-building on York Avenue in upper Manhattan. In those years I had many days of free time since I worked as a free-lance documentary movie cameraman which usually meant having a job only a few days a month.

My first experiments were with 1/4” dowel sticks and fishing line. Using these simple materials brought me back to my boyhood happily alone for hours constructing balsa and tissue model airplanes. I soon advanced from dowels to aluminum tubes and bead-chain. Bead-counting made it easy to measure tension lines, at least to the accuracy of a single bead. (Fig. 4) I quickly learned many things about basic tensegrity structures and how they work.

I moved ahead that Winter with such concentration that by the middle of March, 1960, six months after I began, I was ready to apply for a patent for a collection of previously unknown rudimentary ideas. It was important this time around to have a proper record of what I had invented. I found an expensive patent attorney and a draftsman, the least expensive one I could find, and by March 1960 my patent was applied for. It was not until five years later that U.S. 3169611, “Discontinuous Compression, Continuous Tension Structures”, was issued.

The descriptive first paragraph tells of my optimism and what I hoped was true about the superior performance of floating compression structures. In fifteen pages, including thirty-four figures/drawings, it describes the several ways to expand the X-module. It also describes five different, previously unknown, towers including the three-way tower. (Fig. 5) (I appreciate it greatly whenever engineers acknowledge in their papers where this archetype three-strut column originated.) I included a double-shell dome as well as a faux Eiffel Tower embellished by the draftsman with a tiny human figure to indicate its gargantuan size.

Considering the many technologies from societies of the past such as ropes-and-pulleys, hot air balloons, weaponry, weaving, goldsmithing, origami and the vast knowledge of materials and chemicals that came from the alchemists, is it not remarkable that there never has been a tensegrity craft? Even if only for the delight of children? I can think of no explanation for this except that it never had that famous mother known as “necessity”. But suddenly, today, on the internet, there is a wealth of information. YouTube has many “How To Make a Tensegrity” videos. There are websites devoted to tensegrity and even a specialized Tensegrity Wiki. T*ensegrity-as-a-craft* is here at last.

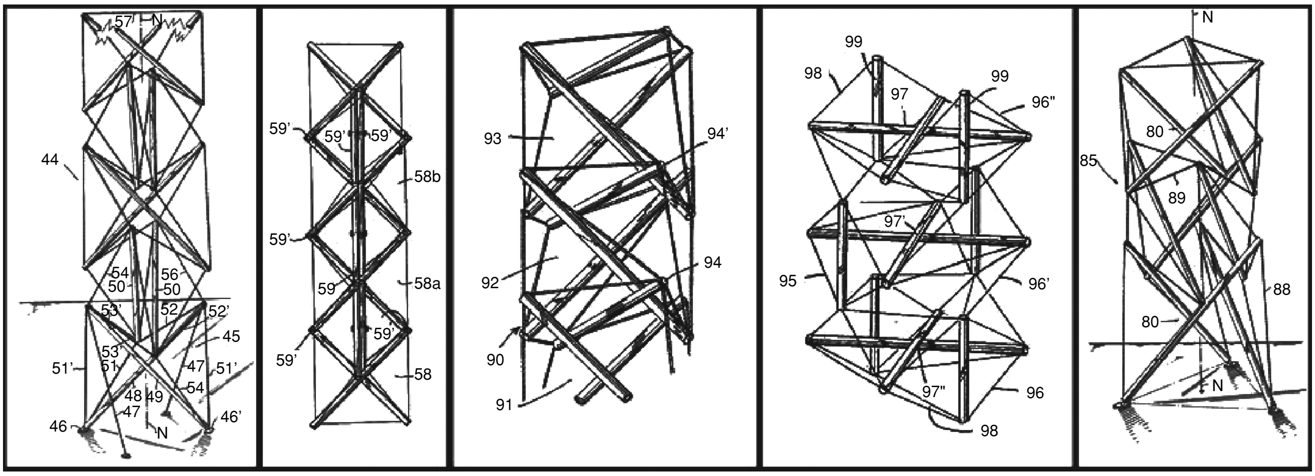


Figure 5. DCCT Towers

But what about patenting in this case, what did I achieve? After going through the legal process several times I see patenting in a different light from the way most people think of it — as a possible road to becoming a millionaire. I am speaking of private inventors not corporations like IBM, Pfizer or General Motors with hundreds or thousands of patents to protect their commercial interests. Years before the internet came along it was necessary to go to the patent office in Washington and pour over stacks of patents to find out if your idea was unique. It was expensive to have a law firm do it so I had the fun of searching all by myself. And I did find it fun. All the U.S. patents ever done and many foreign patents are arranged there according to a classification system that keeps changing and growing. It tries to place ideas in their appropriate category. Some things turn up in odd places such as artificial limbs being classified as “toys”.

I went there several times and spent hours looking and hoping that the brilliant idea I had brought with me had not already been invented by someone else. Searching took me through hundreds of wonderful and wacky ideas. As a continuous record, patent files represent a history of inventions that is neither selective nor interpretive as written history is, where an author chooses to include some examples and leave out others The nonsense of the time is recorded along with the profound discoveries. Almost anything can be patented if it can be shown to be new and useful and it is evident that there has always been the broadest interpretation of what is useful: an airplane made of riveted steel plates with flapping wings?

A patent in the U.S. allows the inventor seventeen years of protection for his idea; or, as patenting is often called, “an invitation to litigation”. He must describe and illustrate his invention and state his claims. The claims, the patent’s legal teeth, allow only what is new and different from existing patents or common information familiar to “those skilled in the art”. From the moment the inventor applies for a patent it becomes available for the public to read. I decided finally that one of the main values of patenting is for the history of the nation, to document inventors’ ideas and discoveries for future generations.

Despite imagining early-on that tensegrity would turn into gold, my patents — all five of them — are for the purpose of publication. Architects, Engineers, scientists and those in other professions have journals and conferences where they can present papers. Artists have art magazines with unintelligible articles written by art critics. So I have applied for patents which give evidence that my ideas were new and original and to fully explain the subject, even though the text is often in stilted legalese. They will continue to be available free for as long as the nation survives. (And one day even my Atom Model will be paid attention to.)

After applying for the tensegrity patent I began to think of planar structures. The X-module itself becomes a plane by repeating modules in x and y directions.(Fig. 6) I first made planes out of three-way and four-way modules which were easy and obvious once I knew how to connect things together. (Fig. 7)

The most remarkable example I had in mind though was an economical structure that amounted to transforming woven fabric into a tensegrity plane. It was during this experiment in fact that I began to identify weaving with tensegrity. For a trial model I used small thin-wall aluminum tubes with holes drilled for connecting monofil tension lines. (Fig. 8a) It was

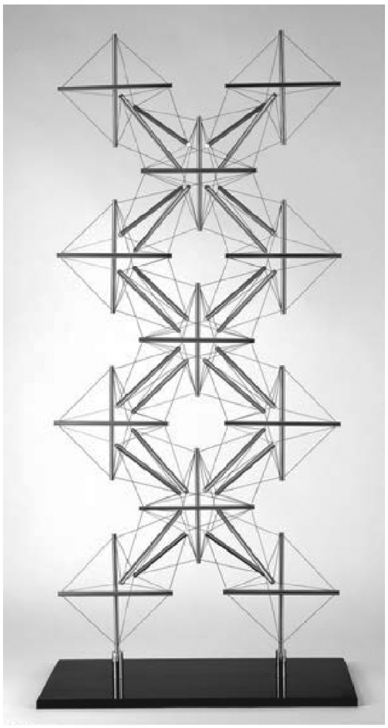


Figure 6. X-Planar Tower

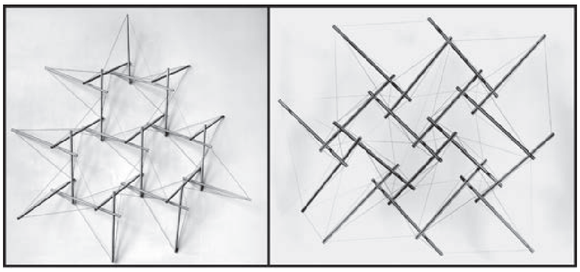
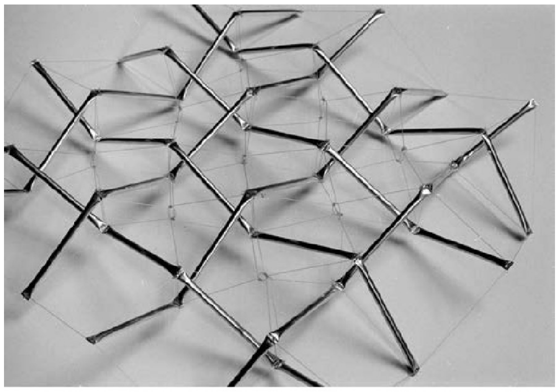


Figure 7. Triangle & Square Planar

(a) Planar Weave



(b) Parts for planar piece

(c) Planar Roof York Avenue

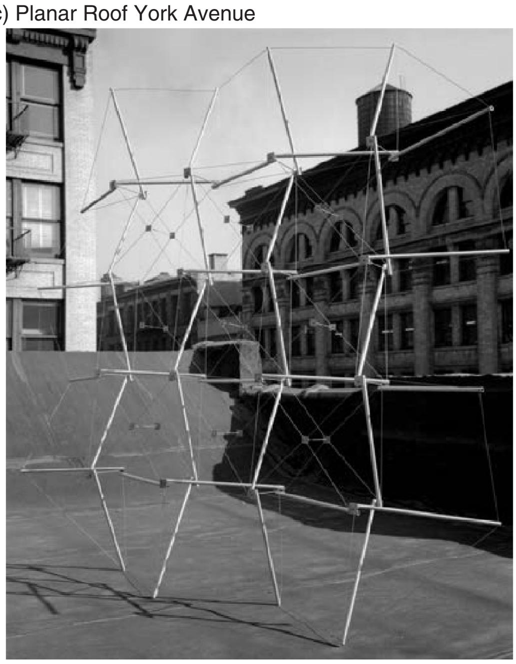


Figure 8.

the sparest system imaginable. To make a larger piece I found a local factory to stamp out steel inserts with holes in the center for connecting bicycle spokes that would act as adjustable tension wires. (Fig. 8b) In those years New York still had many machine industries of all kinds that were soon to disappear along with the rest of U.S. manufacturing.

My planar weave piece was tricky to build because the prestressing had to be symmetrical to prevent the plane from warping. Completed finally, it was but a skeleton, six feet square, weighing only twelve pounds. (Fig. 8c) I finished it on a warm and clear Sunday morning in April 1960 and decided to take pictures of it on the roof of the building where I often photographed things because my studio was filled up with models. I carried the lightweight structure up the flight of stairs and through the steel fire-door to the roof where I set it down by its edge. I took one shot but the only way to get a picture without the neighboring buildings in the background was to place it on the parapet which was about two feet wide — and shoot it against the sky. I set it down, again on its edge, and stepped back to look through the view finder.

Suddenly I felt a strong gust of wind and in an instant I was watching my elegant work tilt backward toward York Avenue. I rushed to grab a wire. Too late. Then, in what seemed like an unreal dream, I saw not only the structure but my brand new Canon Reflex crash to the sidewalk six stories below. Because it was Sunday morning only a few pedestrians were nearby and thankfully no one had been hit by the tubes, wires and camera that all lay scattered on the sidewalk. A woman kindly helped me gather up the pieces as I mumbled some sort of confusing explanation. As people often say "It takes a helluva lot to surprise New Yorkers." In that sad experience I had learned a great deal more about the hazards of gambling than about the practical use of a woven tensegrity plane. I knew at least that the structure was not unbreakable.

At the end of 1960 I moved to a large loft on Spring Street in SOHO (Fig 9) and began building bigger models. The tallest was a tower twenty feet high which I assembled, once again with the free use of the roof. Word was getting out about my structures. A friend, Richard Bender, who taught architecture at Cooper Union, brought his class for a studio visit in order to introduce the new "tensegrity" to his young future architects.

Another friend came by with a friend of his, a writer who worked at *Fortune Magazine*. He wrote a nice article for next month's issue with lush color photographs. It was titled "Sculptures to Build With" and it said that "These ingenious frameworks of wire and tubes may become the architectural framework of the space age... A space station framed according to Snelson's system could be attractive to rocketeers who must count every gram they boost into orbit." Even back then! But I could see how easy it was for Bucky to get his outlandish claims published about sensational tensegrity. And the title reflected perfectly how ambivalent my own thinking was at that time. No one could be more passionate about anything in the world than I was about my captivating structures, yet given my odd position, not being an engineer but schooled in art I was sitting squarely between chairs.

Then, by surprise, I received a commission to make art, to build two sculptures for the 1964 New York World's Fair at the Electric Power and Light Pavilion. Fortune magazine's "Sculptures to Build With", had been noticed and in this case the question, "Sculptures" vs. "to build with", was pre-decided. They wanted sculptures, not buildings which I would have had no idea how to begin in any case. I was excited since it was my first opportunity to construct big works that would be seen in public. One was a seventy-foot high three-way, straight, tower, far bigger and more massive than anything I had done so far, plus it was going to be illuminated by a twelve-billion! candle-power shaft of light pointed straight up through the tower's central axis. I was to be part of the "Brightest Show On Earth" as advertised by the PR people. The second sculpture, was a complex translation of X-modules thirty-five feet wide, that would stand over the entrance to the Pavilion.

Here was a completely new experience. I made exact scale-models and had my arcuate-lip cable-adjusting hubs made by sand-casting. I found a polishing plant and an anodizer to finish the aluminum tubes. In the studio I cut and fixed ends on the hundreds of carefully measured stainless aircraft cables. Then came the trial assemblies. I put the entrance sculpture together in the loft and then the tower, lying on its side. (Fig 10). Finally, a few weeks before the opening date, everything was shipped to the Fair grounds for a remarkably smooth installation. It

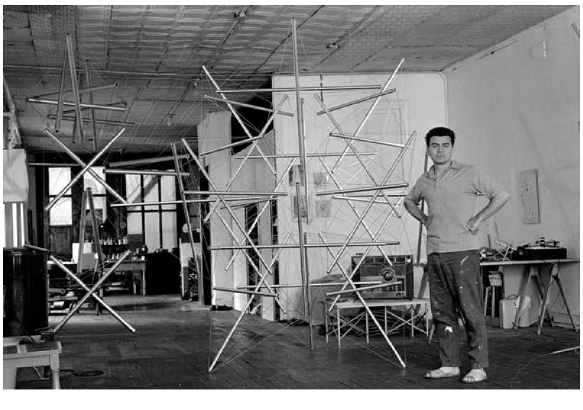


Figure 9. Spring St. Loft 1960

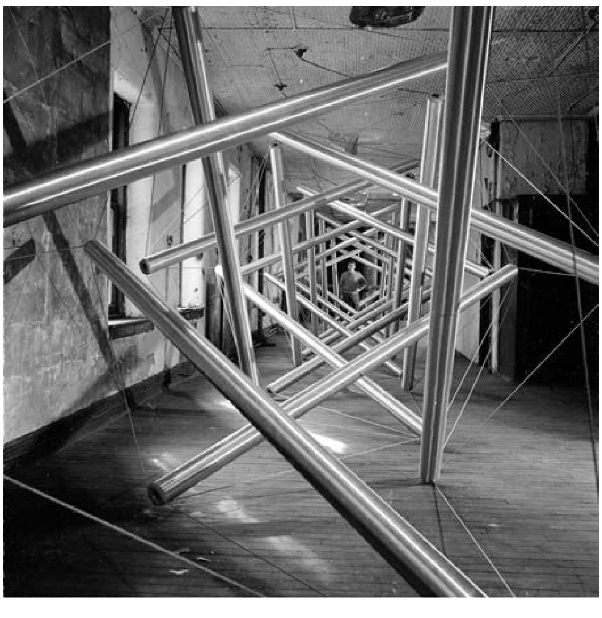


Figure 10. World FairTower Loft

Figure 10 a. Tower of Light 1964

had taken all of ten months. And I was getting paid! The commission covering fabrication and everything totaled $20,000. Quite a lot of money! (Fig 10a)

A month earlier a reporter from the New York Times, Gay Talese, came to the loft to interview the "artist at work" and amazingly, two days later, the article with a photograph of me appeared on the front page. Talese said "an artist named Kenneth Snelson shares his dark, dusty, loft with what appears to be a gigantic grasshopper. Upon closer inspection, however, it is a modern structural design..."

With the pride of a famous son, I mailed the Times clipping to my mother in our hometown of Pendleton, Oregon. She immediately passed the article on to the town's newspaper, the East Oregonian, which announced that native Pendleton artist Kenneth Snelson had created a gigantic grasshopper for the New York World's fair.

A Fair's carnival-environment with so much to see was not the greatest location for an artist hoping that visitors would take a moment to admire and to contemplate truth and beauty. When the lights were turned off a year-and-a-half later and everything was taken apart I was a little sad it was all over but 1964 had been a valuable learning experience.

A few days after the closing, a man phoned me at home to say he had just purchased my two sculptures. I was taken by surprise since I had not thought much about where they would find a home after the Fair came down. I told my new collector that I would be glad to come there and help him take the sculptures apart. "No problem," he said. "we've cut the wires so they're already apart. I deal in scrap and I wonder if you happen to remember the alloy of the aluminum tubes?"

While the Fair was going on an engineer, Nick — whose last name escapes me — worked on the pavilion and also taught at the University of North Carolina, told me that one of his students was looking for a thesis subject and if I liked the idea he could measure the stresses on a structure. I would have to add aluminum inserts on a few cables in order to attach the strain gauge foils. Nick said the student would no doubt come up with some valuable information. It sounded worthwhile so I made a three-way column structure and added the small aluminum plates. After a few weeks went by Nick phoned and confessed that his student had not come up with anything definitive about tensegrity's efficiency but that my tower had "performed quite well". I think it was at this time that I began to have doubts. Just how well would my structure hold up in comparison to an equal-size aluminum step ladder? The only reward from Nick's testing-adventure was a funny photo a friend took of me perched on the tower with its strain gauge plates in place. (Fig. 11)

In those years I began to think a lot about the spatial properties of tensegrity structures, especially as they relate to other matters in geometry's huge house of mirrors; thoughts that lead to what properly educated people in any specialized field might look down upon as metaphysics.

Yet an impulse to make thought-associations—to connect together what may seem like unconnected ideas—is what enables every inventor everywhere to invent new things.

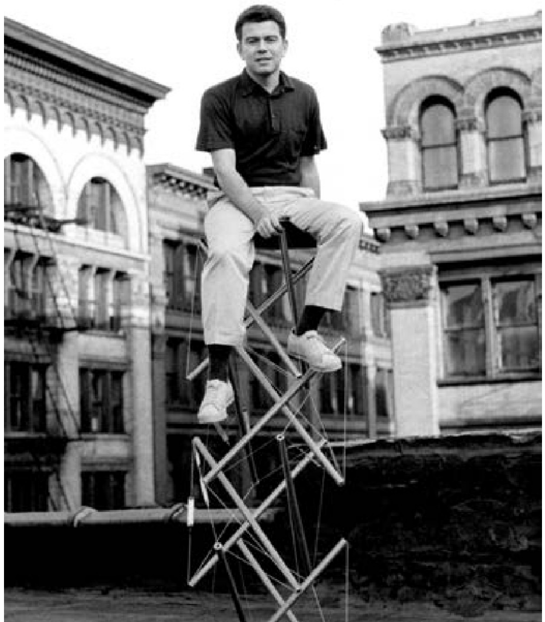


Figure 11. Ken On Tower

I recognized that everything about tensegrity is binary just as opposing tension and compression forces are binary. The primary example of binariness can be seen in the kite frame itself where the two crossed sticks create two axes, one clockwise and one counterclockwise. (Fig. 12a) If you slide two fingers toward the intersection along the two struts your hand will tend to rotate either in a right-screw direction or a left-screw direction depending on which of the two axes you start with.

In the six-strut tensegrity, four of its eight face-triangles are clockwise helixes and the other four are counterclockwise, alternating over the figure like adjacent squares on a chessboard. (Fig. 12b) This principle of alternating rotating directions is found in all tensegrity structures and it is fundamental to how they work.

It is also how fabric-weaving works. There are two fundamental types of weaving: the standard two-way plain weave and the three-way triangle/hexagon weave used mostly in basketry. In each of these weave forms the adjacent polygons rotate right and left, alternately, just as in tensegrity figures. (Fig. 13)

The basic weave cells of two, three, four, five and six crossings can be translated into basic tensegrity cells. (Fig. 14) The tensegrity helical phenomenon and its similarity to weaving suggested that it might to be possible weave rods of some kind in three dimensions. I tried it using thin dowel sticks and happily found that it works. These weave structures, or woven space-frames, are composed of polyhedra whose edges, instead of coming to a point at the vertex, bypass one another in a helical rotation. (15) They are "weave-polyhedra". I discovered three basic woven 3D patterns: One is composed of weave-octahedra alternating in space with weave-cuboctahedra. (Fig 15a) A second type is composed of weave-tetrahedra alternating with weave-truncated-tetrahedra. (Fig 15b) A third 3D weave is rectilinear, analogous to six-strut tensegrity figures repeated in space. Because the cubical weave is not triangulated it is a wobbly space-frame. I constructed examples of each type in 1964. I took pictures and set the prototypes aside. (Fig 16)

My woven space frames traveled with me for nearly forty years as I moved my studio from place to place. In 2002 when the internet made it easier to do searches I looked all over the web for 3D weaving and I was surprised to find no such thing. Since I had never published a picture or a description of three-dimensional weaving I decided to apply for a patent to record that it was a new idea. US Patent number 6,739,937 "Space Frame Structure Made by 3-D Weaving of Rod Members" was approved two years later.

I have described weaving as the "mother of tensegrity" although it is fair to ask which is the chicken and which the egg.

Another example of binary forces associated elegantly with tensegrity geometry concerns the north and south polarity of magnets which I found by trying to visualize what it would look like to transform the helical, static, motion of the six-strut tensegrity's eight face-triangles into propellors or circles representing clockwise and counterclockwise rotation. In a series steps—too many to describe here—I discovered that round magnets with poles on opposite faces like heads and tails of coin will snap together edge-to-edge in certain numbers to form closed "circlespheres". (Fig. 17) When one of the magnets is made to revolve by hand the others around the sphere follow, rotating as a single gear-train.

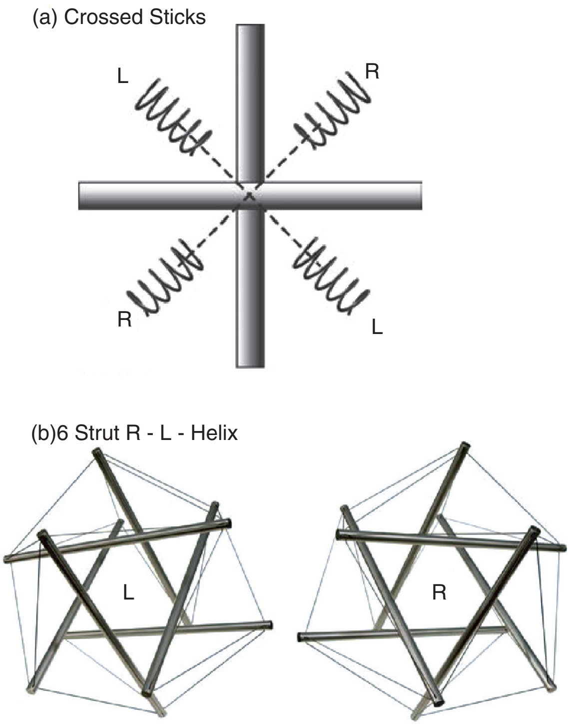


Figure 12.

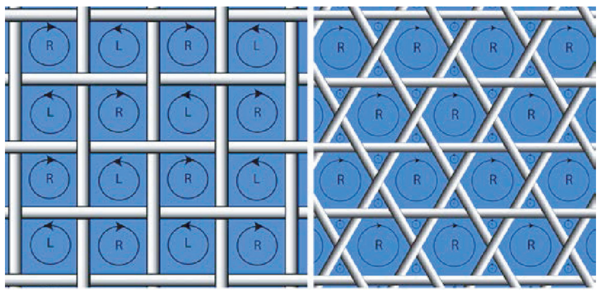


Figure 13. Square & Hex Weave Mar27

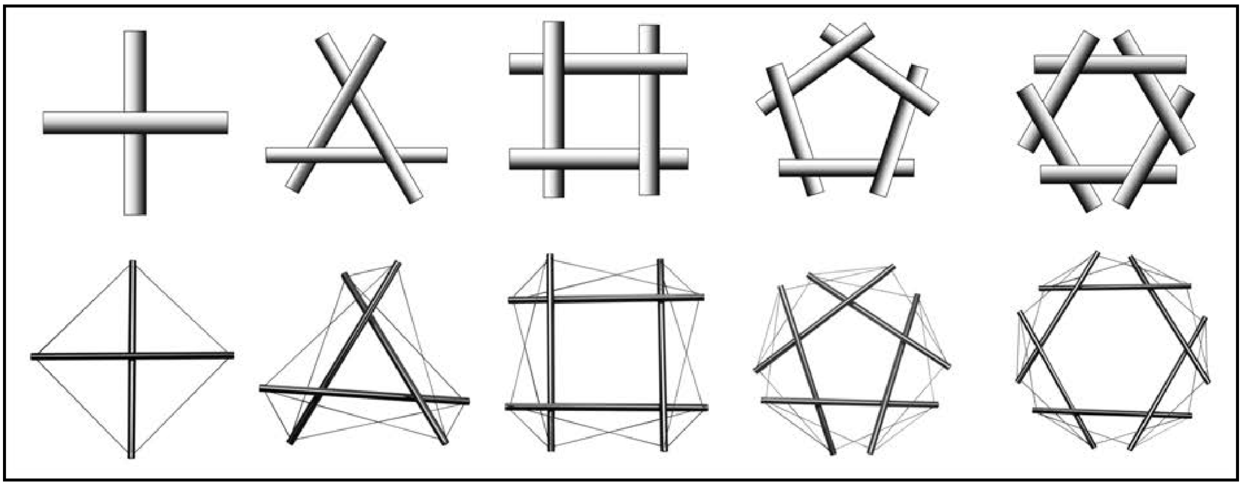


Figure 14. Tensegr. & Weave Cells

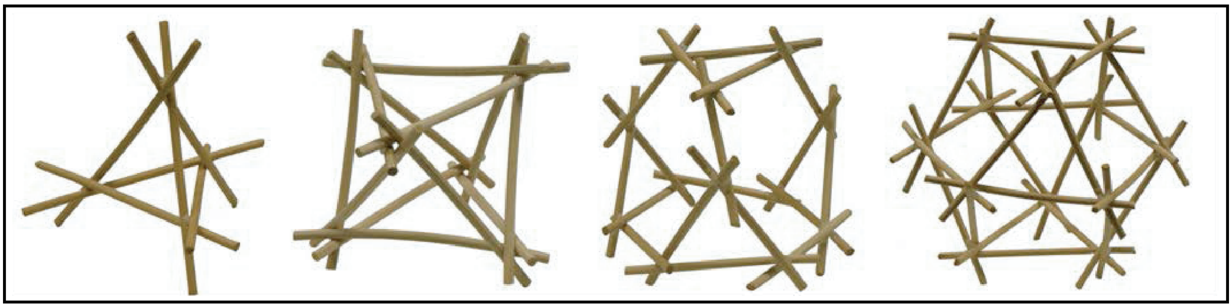
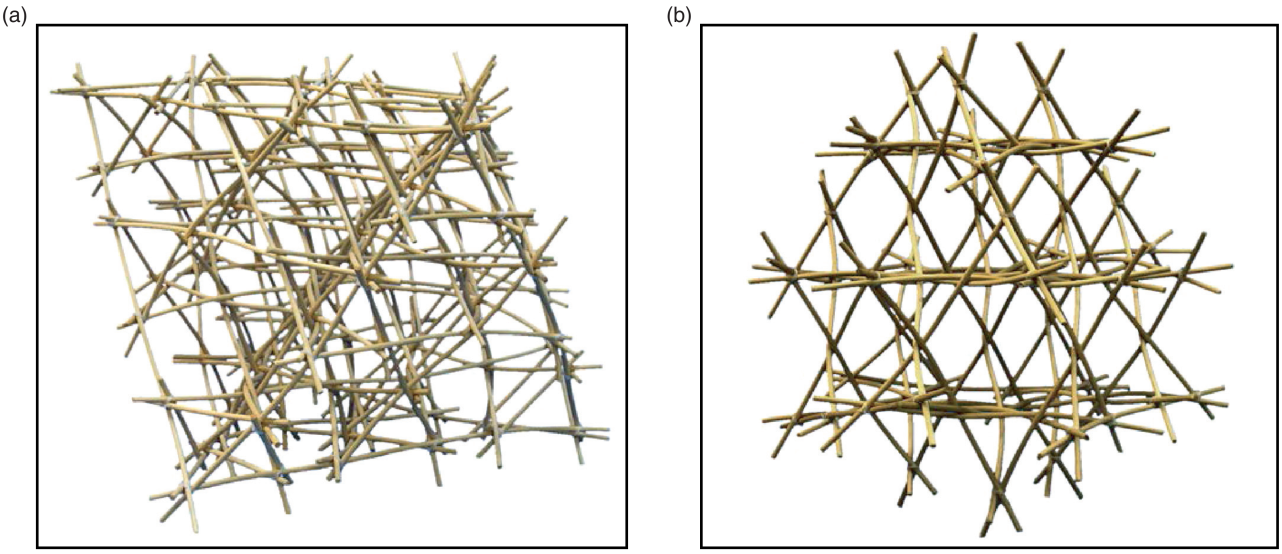


Figure 15. Four Twist Figures



Figures 15a & 15b. Octa and Tetra Weave

This subject, magnets-on-spheres, which came directly out of tensegrity, took me along the path to my long-running open-ended artwork I call "Portrait of an Atom"[1].

I discovered also that certain Platonic and Archimedean polyhedra can be constructed out of polygon-shaped magnets with alternating north and south faces. (Fig. 18)

[1]My atom model is fully described and illustrated at my websites — www.snelsonatom.com and www.kennethsnelson.net; also in two atom patents: US Patent 3276148 and US Patent 4099339.

All of these ideas came from my following the thread of the 1948 X-Piece which would seem like a far cry from speculations about the atom's electronic architecture. These side-adventures are cousins to their prototype, the kite-frame with its built-in prestressing, its cross-over intersection, its binary helical axes and its ability to repeat in space, cell after cell, ad infinitum.

I have come to believe that this reversing or alternating principle in its many manifestations is the prime means used wherever nature requires separate parts to be connected together to form a new whole.

Figure 16. Ken with Weave Space Frames

ART AND TENSEGRITY, QUESTION AND ANSWER

Since the 1960s many engineers and architects have contributed to the tensegrity culture by analyzing how such structures perform and by inventing ways to apply tensegrity for practical use. And many people consider tensegrity to belong properly to the study of engineering. In regard to my work they earnestly ask that well-worn question, "but, is it art?". Mr. Fuller himself was the first to assert that tensegrity should not be used as art yet the only visible tensegrity structure attributed to him is a "sculpture" that hangs in the Engineering Centers building at the University of Wisconsin.

My first solo exhibition was in 1966. When the show opened the "is it art?" question was resolved in a day because the reviews about my sculptures at New York's Dwan Gallery were laudatory. By the luck of perfect timing the pendulum had swung at that moment in the direction of geometric painting and sculpture; and the movement was soon given a new name, "*Minimalism*". Because the art-world moves ahead in a way like Haute Couture, fickle in the same way, the celebration of *Minimalisim* lasted less than three years, to be replaced by something new called *Earth Art* which was soon replaced by *Conceptualism* which was soon replaced... I watched the art scene move forward like a ping-pong ball bouncing on a table with ever reduced importance at each bounce.

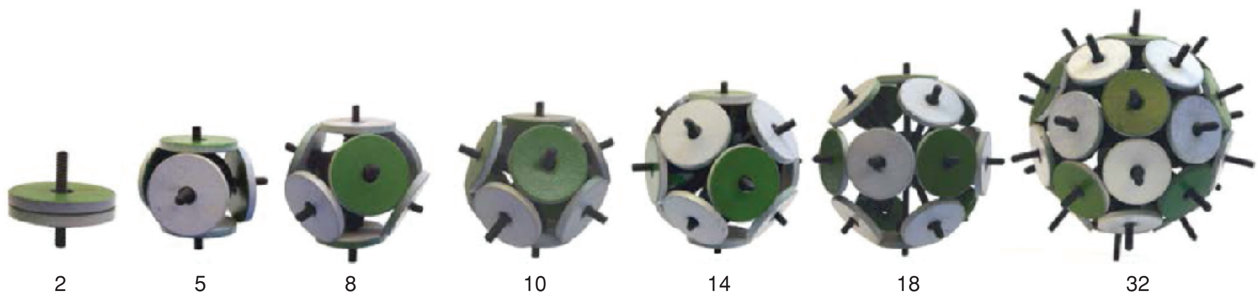


Figure 17. Seven Magnet Spheres

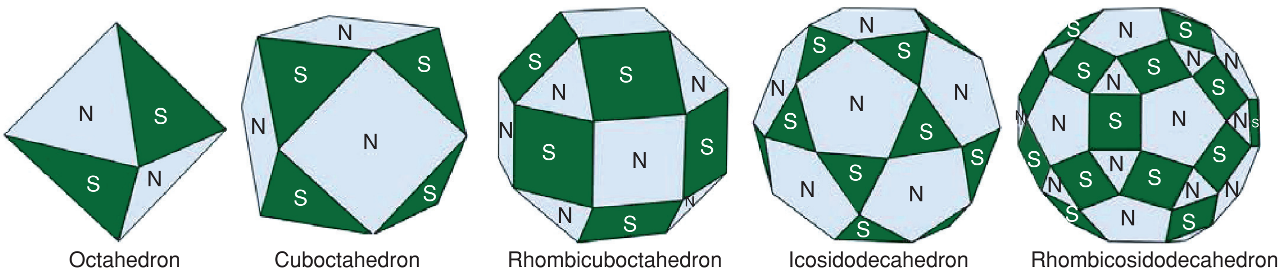


Figure 18. Magnet Polyhedra

Now, half-a-century since my first exhibition, art has gone through many fashion changes and now seems to have spread out into a wider support of many styles, largely because there are thousands more artists than there were in the 1960s.

This paper's narrative is about the beginning of tensegrity, my primary schooling. I look forward to writing more about it. Some wise person observed that "Youth creates the melody, the middle years add the harmony. In old-age, grace-notes."

REFERENCES

Kenneth Snelson is represented by Marlborough Gallery, NY.

Snelson, K 1965, Continuous Tension, Discontinuous Compression Structures US Patent 3169611

Snelson, K 1966, Model For Atomic Forms, US Patent 3276148

Snelson, K 1978, Model For Atomic Forms, US Patent 4099339

Snelson, K 1997, Magnetic Geometric Building System, US Patent 6017220

Snelson, K 2004, Space Frame Structure Made By 3-D Weaving of Rod Members, US Patent 6739937

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