Historical Perspective on John Kirk's Tensegrity Geometry Research

In 1948, a class of structures was invented by Kenneth Snelson while attending a workshop at Black Mountain College under the auspices of Buckminster Fuller. The distinguishing feature of these forms is separation of the structural functions of tension and compression into separate physical components of the final construction.

In the unsuing years, Snelson pursued a successful career as a sculptor and installed many of these structures in architectural settings. These sculptures all embody great beauty and grace and tend to inspire a kind of awe in the observer because of their departure from the traditional "brick-upon-brick, up from the solid foundation" building metaphor. They seem to hold their shape magically — as if they somehow "shouldn't work", structurally. Even in structures that include tension in important ways (such as suspension bridges and sailboats), the convention has been to build a "strong, solid, central tower" from which the details may be "hung" in tension.

Buckminster Fuller was intrigued with understanding and popularizing the principles demonstrated by this kind of construction. He contended that these principles are the implicit basis for all structural form in the universe, and at all levels of scale (from the sub-atomic, through the architectural, to the interplanetary). For one thing, the principle helped a great deal in conceptualizing and understanding the problems encountered by the many people who tried to build the geodesic domes he had invented and popularized. The joints, where several structural components connected to each other, tended to work themselves apart thus letting-in rainwater, et cetera. The orthogonality (right-angled-ness) of joints in conventional structures simplifies the distribution of forces in a way that allows a number of structural considerations to be neglected in these cases.

Fuller coined the term, *tensegrity*, which he applied to both the principle and also the special class of constructions that explicitly articulate it. The term is easy to say, while shortening the two-word "tension integrity", which emphasizes role of tension in assuring structural integrity of a construction. A feature Fuller notes about the special class of structures called *tensegrity* is that the tension components (cables, strings, tendons) all interconnect to form a continuous network spanning the entire construction, while the members that bear compression (struts, sticks, spars) are each isolated from the others and each connected directly only to tension members. Fuller refers to this phenomenon as the struts being *islands* in a *sea of tension* cabling.

My own work with what Fuller termed *tensegrity* originated in the 1960's due to Fuller's lament that the existing computerized finite-element analysis methods for doing engineering calculations gave inadequate results for the purposes of building geodesic domes or other tensegrity-based forms. I didn't have the background to confirm whether those methods were inherently inadequate, or whether instead the problems might have been due to other causes. I had, at that time, done the computer implementation work for this kind of software product and could see value in the idea of resolving all forces (including torque, bending, shear, etc.) into conceptual components of only pure tension or pure compression.

The issue in general is that simplifications must always be made in order to construct a conceptual model that will be helpful to people in coping, planning, designing, etc., in the real world with all its complexity. The hope is that the model will include all of the relevant features of the real world situation while eliminating the myriad detail that is irrelevant to the purposes at hand. The issue in specific, here, might be that some aspects of structural behavior were not being explicitly modelled by conventional finite-element analysis methods, but were being accounted for by fixed-value "fudge-factors" chosen large enough to account for the range of variation of certain parameters. Perhaps a tensegrity analysis would allow conceptualization at a finer degree of granularity, substituting more detailed modelling for fixed-value estimates.

My thought at the time was that, assuming one of Fuller's university students had done something like a PhD dissertation on the mathematics of tensegrity, I could just incorporate those results into one of the computerized engineering programs for analysis and design. Perish the thought! I discovered, over the years, that almost everyone who has worked with tensegrity has build or drawn pictures of the forms by "cut and try" methods, based on symmetry considerations, etc., but nearly no-one has done much theoretical work in the area. (In the last few years, several university efforts have begun to study this class of structures, but I am at this point embarrassingly ignorant of the details of their work.)

In a nutshell, my approach has been to solve the force-equilibrium equasions (for a tensegrity structure which holds a stable shape) which state that all the vector forces add to zero for each joint where tension and compression elements connect. Such a statement defines what it is to be a tensegrity form in the simplest possible way. Such a statement, written in mathematical format, becomes an object which can be manipulated and re-arranged according to mathematical rules, until a resulting form emerges which directly reveals exactly the information one needs to construct the tensegrity form itself. For instance, if you decide to make one of these structures with a strut whose length is two feet, the resulting formulas tell how long to make the corresponding cables, and at what locations in space each of the joints will reside.

At present I have results for the six-strut form which corresponds to the tetrahedron and its dual tetrahedron, and for the twelve-strut form which corresponds to the duality between the octahedron and the cube. Current status of this work-in-progress is more fully described elsewhere, as are plans for further efforts.