The invention is a single and/or musical instrument based on Tensegrity structures. It shows how a simple retying of a traditional Tensegrity, comprising a plurality of single shaped and/or multi-shaped struts, results in the creation of a single and/or multi-toned musical device, in which the compression struts of traditional Tensegrities become musical instruments. The simple retying involves moving the tie point of the struts from their usual place, at the strut ends, into one of the nodal minima's for the desired strut resonance mode. Another way of viewing this transformation is to imagine lengthening the strut beyond the ends where the strut is tied until the tie points are at resonant nodal minima's. What is left after the transformation is that all of the structural properties of a Tensegrity are maintained, while any of the struts that were retyed in the transformation become musical chimes that sound out a musical note, or combination of notes when struck with a playing hammer.
Figure 1.
Figure 16
**TENSEGRITY MUSICAL STRUCTURES**

**FIELD OF THE INVENTION**

[0001] The present invention pertains generally to the creation of musical instruments using Tensegrity structures, and more particularly, to a technique which enables most known Tensegrity structures to be constructed so that each of the compression struts become high “Q” resonators which are the key components of the new musical instruments.

*Q* is the ratio between the stored energy and the dissipated energy over a cycle.

**BACKGROUND OF THE INVENTION**

[0002] Man has been making music and creating musical instruments since the beginning of recorded history. The present invention uses a novel approach in the building of a recently discovered architecture called Tensegrity to create new percussion, string, or wind instruments. The present invention specifically illustrates how to build a chime set, which can be hammer driven like a xylophone or wind driven as a wind chime.

[0003] It is the express purpose of this patent to add to the growing body of functional uses for Tensegrity. Heretofore Tensegrity has been primarily used for sculptures and art. Many art examples can be found in the literature. Buckminster Fuller and others, such as the faculty of the University of Florida, have pioneered some functional uses of Tensegrity in the building of both permanent and portable living units. Still others are making inroads into the use of Tensegrity for furniture and lighting fixtures. However, by and large the use of Tensegrity has been mostly for Art and education.

**SUMMARY OF THE INVENTION**

[0004] What is Tensegrity, and how can a careful retying of a standard Tensegrity structure create a musical instrument? The introduction to this invention answers that question in three parts: first by defining Tensegrity and giving a brief description of its origin; then by examining the key components of a musical instrument and giving it a concise functional definition; and finally putting those two parts together to reveal what a Tensegrity Musical instrument is.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0005] FIG. 1. T-Icosahedron, the original eight strut Tensegrity. The structure is tied at the strut ends and all the resonant modes of the struts are suppressed and the unit is not a Tensegrity chime.

[0006] FIG. 2A. Is a three fold “Twisted prism”, the simplest Tensegrity, consisting of the minimum number of elements, three struts and nine tensional elements. Here only compressive forces are allowed on the struts. It is a standard Tensegrity tied at the ends of the struts so all of the overtones including the fundamental are suppressed and the Tensegrity is not a chime.

[0007] FIG. 2B. Shows detail of the strut end showing continuous tensional elements. If the strut is only supported in two points, this arrangement will not allow bending or torsional forces on the struts

[0008] FIG. 2C. Shows detail of the strut end illustrating three tensile units not attached to the same point, but attached to a ring on the strut defined by a cross-sectional cut perpendicular to the cylindrical axis of the strut. This multi-point tensile element attachment acts almost like a single point attachment except that it allows torsion forces in the strut, and is therefore said to be functionally continuous.

[0009] FIG. 2D. Detail illustrates a discontinuous group of tensile elements attaching to a strut end, which allows torsion and bending forces on the strut.

[0010] FIG. 3. Is a Tensegrity cube with eight separate functionally continuous tensile groups of nine elements each. These tensile groups are called Tensegrity joints. Here again the ends of the struts are constrained and all resonant modes of the strut are dampened.

[0011] FIG. 4A. Resonating tubular strut tied at all four nodal points of the struts third overtone, such that the third overtone is allowed to oscillate freely, while all other overtones including the fundamental are strongly suppressed.

[0012] FIG. 4B. Resonating tubular strut tied only to the outer two nodal points of the resonators third overtone, behaves as resonator in FIG. 4A only the overtones are not as well suppressed and the strut is not as firmly supported mechanically.

[0013] FIG. 5A. Is a three fold “twisted prism” whose struts are tied together at all four nodal points allowing the third overtone to oscillate freely, while strongly dampening all other strut overtones. This Tensegrity chime unit illustrates a musical chime with redundant tensile elements added to facilitate overtone dampening and increased structural integrity.

[0014] FIG. 5B. The three fold “twisted prism” shown here produces the same musical note as FIG. 5B. It is an example of a Tensegrity chime with a functionally continuous set of tensile elements tied only at the outer pair of nodal points of the struts third overtone. This again allows the struts third over tone to oscillate freely while suppressing all other overtones. This arrangement, while still suppressing all other strut overtones does so less vigorously since the inner pair of nodal points are not constrained as they are in FIG. 5A. It is also a mechanically weaker structure then the Tensegrity chime in FIG. 5A.

[0015] FIG. 6. Illustrates a five fold “twisted prism” whose struts are tied together with a continuous set of tensile elements. All of the struts resonances are dampened and the Tensegrity is not a chime set since it is standard Tensegrity tied together at the endpoints of the struts.

[0016] FIG. 7. Shows a top view of a three fold “twisted prism” Tensegrity tied as a chime unit. The tubes are tied together at the fundamental modes nodal points allowing the lowest order to resonate.

[0017] FIG. 8. Side view of a three fold “twisted prism” tied at the nodal points of the tubes fundamental mode. Only the lowest order mode can oscillate freely in this chime unit as all other overtones are suppressed.

[0018] FIG. 9. Top view of a five fold “twisted prism” Tensegrity chime. Here again, the struts are tied together at the nodal points of the struts fundamental mode and all other overtones are suppressed.
[0019] FIG. 10. Illustrates a five fold “twisted prism” Tensegrity chime assembly. The tubes are tied together at the fundamental modes nodal points, allowing the lowest order to resonate. All other overtones are dampened, so that if one of the struts is struck it rings out with its pure fundamental tone.


[0021] FIG. 12. Illustrates a three fold “twisted prism” tied at the nodal points of the struts fundamental mode. The chime assembly is attached to the base at the midpoints of the bottom tensile elements. The floating nature of the struts is maintained as the unit is attached to a stand. Since the struts still float in a tension web they can still resonate freely when struck with a mallet. This allows the structure to become a musical instrument that can be set down on a table and played.

[0022] FIG. 13. A five fold “twisted prism” tied at the nodal points of the struts fundamental mode. The chime assembly is attached to the base at the midpoints of the bottom tensile elements. The floating nature of the struts is maintained as the unit is attached to a stand. Since the struts still float in a tension web they can still resonate freely when struck with a mallet. This allows the structure to become a musical instrument that can be set down on a table and played.


[0024] FIG. 15A Shows an isometric view of a resonating flat bar suspended at the fundamental points.

[0025] FIG. 15B Side view of a resonating flat bar illustrating the fundamental free beam mode in oscillation. First overtone frequency =F1

[0026] FIG. 15C Side view of a resonating flat bar illustrating the second free beam mode in oscillation. Second overtone frequency = 2.76F1

[0027] FIG. 15D Side view of a resonating flat bar illustrating the third free beam mode in oscillation. Third overtone frequency = 5.40F1

[0028] FIG. 16. Shows a single tube illustrating the fundamental mode in oscillation.

[0029] FIG. 17. Illustrates a five fold “twisted prism” Tensegrity chime assembly hung as a wind chime with a hanging spherical striker and wind sail.

[0030] FIG. 18. Is a three fold “twisted prism”, as in FIG. 8, whose struts are tied together at the nodal points of the tubes fundamental mode, except that the tying is done with one continuous tensile element instead of with a set of nine discrete tensile elements. Here the tensile element is truly continuous, where as the “twisted prism” shown in FIG. 8 is, as defined in this patent application, to be functionally continuous. One of the purposes of including this drawing in the invention is to illustrate another method of Tensegrity tying. The invention is for all and any method of Tensegrity tying.

[0031] FIG. 19. Shows a dual mode resonator with independent horizontal and vertical oscillation in a single rectangular cross section.

[0032] FIG. 20. Illustrates a Tensegrity cube with continuous tensional elements.

[0033] FIG. 21. The Needle Tower shown here is permanently exhibited in the Hirshhorn Galleries outdoor sculpture garden, in the Smithsonian, in Washington D.C. It is a 60 foot Tensegrity sculpture. The Needle Tower, like all Tensegrity structures defined in this invention can be made into a musical instruments by retreating the struts at their nodal points. That is, the Needle Tower illustrates a Tensegrity that could, by applying the teaching of this invention, be converted to a Tensegrity musical instrument. Note here that the nature of this sculpture, with its progressively decreasing strut size would naturally become multi-tonal during the conversion process taught by this invention.

DETAILED DESCRIPTION

[0034] During the course of this detailed description the following will be developed and presented: the history of Tensegrity, the ambiguities in the definition of Tensegrity; a specific definition of a generalized Tensegrity; and a concise functional definition of a musical instrument. The invention is shown to be any musical instrument formed from a described specific tying of any generalized Tensegrity as defined here. Additionally, several examples of the preferred embodiment will be described and illustrated.

1) What is Tensegrity?

[0035] a) Tensegrity structures were invented by the well-known artist/sculptor Kenneth Snelson in 1948 and later named Tensegrity by the iconic inventor Buckminster Fuller in 1953. Both of these Tensegrity pioneers took out early Patents:


[0038] b) The word Tensegrity comes from the combination of tension and integrity; Buckminster Fuller defines Tensegrity as the balance between discrete compression members and a continuous tension member, which joins them together.

[0039] c) A traditional Tensegrity structure is composed of struts in compression connected at their ends with tendons tied in tension in such away that the struts are held apart.

[0040] i) The result is a whole unified object that consists of an integrated system of isolated struts held in suspension between discrete or continuous, tensional, string like elements.

[0041] ii) The struts are always discontinuous and generally rigid. That is, none of the struts touch each other and usually only support compressive loading. Contrasting with the continuous tensional elements that only support tension loading. The struts figuratively float in a sea of string like tensional elements.

[0042] iii) The whole object now behaves like a cooperative unit rather than a collection of separate parts that happen to be attached physically together. Because of the inherent symmetry in construction of
the structure internal stresses are stored within and redistributed between the wires and struts such that the struts are in compression only and the stored energy serves to give shape to the structure and hold the struts forcibly apart.

[0043] vi) Additionally the said cooperative nature of the Tensegrity unit provides load sharing when one or more of the elements is externally stressed. Under such an external stress the elements of the structure respond and interact with each other to help share the load by redistributing and absorbing the offending stress among themselves. Resulting in an overall light weight, robust, and flexible structure.

[0044] v) This stress spreading property of Tensegrities is accomplished through the tensile elements that the struts “float” in. When an attempt is made to put compressive, bending, shear, or torsion load on the Tensegrity the “floating” nature of those struts cause the stressed struts to yield in the web of wires in which they are contained. This web of wires transmits the bulk of the offending stress to the adjacent struts as the wires attached to the stressed struts pull on said adjacent struts. The adjacent struts, in turn, transmit the stress they receive to their respective adjacent struts. This process of passing on applied bending, shear, compressive, and torsion strut stresses to adjacent struts through the struts attached to tensile elements continues through the entire Tensegrity in a wave-like manner until an equilibrium is reached where all elements both struts and wires share the applied stresses.

[0045] vi) In a similar manner, when a tensile element of a Tensegrity is pushed or pulled sideways the wire is not stretched, as it would be if it were a part of a traditional structure such as a spoke in a bicycle wheel. Rather than stretching, the wire ends pull on the wires and struts they are attached to. This pull relieves some of the stress applied, by transferring that stress to those other elements it pulled on. In turn, these secondarily stressed parts transmit the stress applied to them to their own adjacent elements. Again, this stress reduction process continues in a wave-like manner until equilibrium is reached where all of the elements of the Tensegrity share the initial offending stress.

[0046] vii) This stress sharing property is primarily, though not entirely, accomplished by the wires, the tensile elements. The continuous nature of the tensile elements facilitates this load sharing Tensegrity property. Tensegrities are generally said to be structures that have a single continuous tensile element, or more accurately a continuous set of discrete tensile elements. To see this, take a look at the original Tensegrity, a Tensegrity-icosahedron (FIG. 1), where you will notice that a set of tensile elements physically continuous, forms a web. The tensional elements are made up of a single string or many strings tied together. To further illustrate, imagine you were as small and agile as ant, then the tension elements are physically continuous if you could walk or climb over the entire length set of the tensile elements without ever leaving them. On the other hand, look at FIG. 3 and FIG. 5B which are not strictly Tensegrities as defined by Kenneth Snelson, the founder of Tensegrity, because the entire set of tensile elements are not continuous. FIG. 3 contains eight separate groups (“Tensegrity Joints”) of nine functionally continuous tensional elements which are all required. FIG. 5A has two separate groups of three continuous tensional elements which are structurally redundant and not required to hold the struts apart. Finally FIG. 8 and FIG. 10 show Tensegrities whose tensile elements are physically discontinuous, yet are functionally continuous. Here the tensile elements are separated for ease of manufacturing and act nearly as if they were continuous. The break in continuity has the effect of potentially introducing torsion and bending strain into the rigid struts. The struts in a “pure Tensegrity” can only hold compression strain due to the way they are suspended in two points in the tensional element web. The larger body of Tensegrities defined in this patent can have any of the Tensegrity classes described above. They have a fully continuous, functionally continuous, or even fully discontinuous tensile element. Furthermore the larger body of Tensegrities defined in this patent can have struts of any material or shape, and are specifically not limited to the usual elongated shaped struts. Also, the Tensegrities described in this patent can have struts with any number of tensional elements attached to them.

[0047] viii) The definition of a Tensegrity as defined by this invention description is: a tying of rigid or semi-rigid struts that can support compression and/or bending and/or torsion, strung together so said struts “float” separately from one another in a web of tensional elements.

[0048] ix) It is important to note here that the said continuous element must also be physically attached to the struts at the wire-strut intersection points (even if the attachment is frictional) for the Tensegrity to remain together. That is, if a single string representing the single tensional element was threaded through all of the end-points in the Tensegrity icosahedron (FIG. 1), for example, to make all of the proper interconnections between the struts, but were not attached at said end-points the structure would self collapse. This collapse releases the energy stored in the residual tension of the wires and the residual compression, bending, or torsion stored in the struts. In a Tensegrity the tensional element is usually though not necessarily continuous. However in either case, it is required to be affixed to the points where it contacts the struts.

[0049] x) As mentioned above, the Struts of a Tensegrity are always discontinuous. However, not all Tensegrities have a physically continuous tensional element. The tensional elements of some Tensegrities are continuous while the tensional elements of other Tensegrities are discrete pieces. In some cases the tensional elements are discrete, yet functionally act as though they were continuous (as described in section “VII” above on pages 9 and 10). For example, if the tensional elements that attach to each end of each of the three struts in the simplest
Tensegrity, the “Twisted Prism” (FIG. 2A), were attached separately to the radial perimeter of each strut end (FIG. 2C), the structure would behave as though the discrete tensile elements were piecewise continuous. I define that is functionally continuous. If the same Tensegrity shown in (FIG. 2A) were tied at the strut ends as shown in (FIG. 2D), then structure is defined as having discontinuous tensile elements. The Tensegrity Cube (FIG. 20) is made up of one single continuous element attached firmly at each strut end and the Tensegrity cube is defined as having continuous web of tensile elements. In another case a Tensegrity could even have some of its elements removed so that the structure would in general collapse under gravity and the struts fall in together. However if the structure is suspended from cables appropriately then the struts would spring lightly back apart as gravitational forces make up for the missing tensile elements when the structures. I call this a “Semi-Tensegrity” and include it in the general class of Tensegrities that can be converted to a musical instrument by the method taught in this invention. That is, even this flaccid gravity supported Tensegrity will make a Tensegrity Chime.

xi) On the other hand, well know Tensegrity mathematician, Robert Burkhartd has shown a Tensegrity cube where each of the cube’s eight corners have their own separate independent continuous nine element tensile unit. He calls this corner unit a “Tensegrity Joint”. The result, illustrated in (FIG. 3), is a Tensegrity structure whose strut elements are made of twelve sticks that act as discrete compression elements forming the cube’s edges, while the vertexes are formed by eight 9-element independent continuous tensile units. At each of the cube’s corners one of these independent continuous tensile units bind the sticks together in a manner in which the sticks don’t touch each other. It is interesting to note that it is possible to build a Tensegrity Cube where the Tensional elements are continuous. These structures are more common and have been built and displayed by others including Buckminster Fuller and Robert Burkhartd (see FIG. 20 for illustration of a Tensegrity Cube with a set of tensile elements that are continuously connected). For the purposes of this invention, both of these “Tensegrity Cubes” are considered Tensegrities that can be restrung as a musical instrument as will be described in this document.

xii) In a similar manner a newly created Tensegrity Musical Instrument may have a strut tied in many (four for example) places in such a way that the tensional element ends up piecewise continuous as in the Tensegrity cube shown in (FIG. 3). There can be musical reasons that additional strut tie points are added and these additional tie points may, while serving their musical purpose of nulling a particular resonance mode of the strut, end up creating additional tensional elements that are redundant from a structural point of view. These redundant tensional elements, like the center two in (FIG. 4A) will likely go from strut to strut without touching any of the other tensional elements, as in (FIG. 5B), and thus make the group of tensile elements for the Tensegrity discontinuous. In (FIG. 5B) for an example, the simplest Tensegrity (FIG. 5A), with functionally continuous tensile elements, is converted to a Tensegrity with discontinuous tensile elements, by the addition of two triangular groups of tensile elements to the top and bottom of the structure. The single tubular strut shown in (FIG. 4a) is an illustration of a resonant tube tied in four separate places instead of the usual two places to assist in nulling out or damping the fundamental mode while allowing the 3rd overtone of the of the tubular strut to exist unimpeded. When an elongated strut of a Tensegrity is constrained, with tensional elements, at the four nodal minima’s of its 3rd overtone, as illustrated in FIG. 4A, the fundamental tone and all other overtones are suppressed. The two middle attachments on the strut, which may be redundant from structural point of view, serves the function of increasing the damping of the fundamental mode and all overtones except the 3rd. The purity and sound quality of the Tensegrity chime is improved over a free hanging chime because of suppression of non-harmonic overtones of the chime. It is the nature of a percussive chime to have non harmonic overtones. For example, if the fundamental tone of a bar of rectangular cross section is F1, then the second overtone F2=2.76*F1, the third overtone F3=5.40*F1, and the fourth overtone F3=8.93*F1. The typing of a chime with other chimes into a Tensegrity improves the quality of its sound by filtering out the offending overtones. This patent teaches that by typing of the struts at the natural nodal minimums of the mode or overtone desired, that the desired mode is enhanced while all other modes are filtered out. This is one of the reasons the definition of a Tensegrity has been broadened in this patent to include discontinuous tensile element typing as well as continuous typing. Also, a discontinuous typing such as, but not limited to, the Cube in FIG. 3 may allow easier access to the individual chime strut elements when playing them by striking them with a mallet. In general the addition of discontinuous typing allows greater degrees of freedom in the construction of Tensegrities, and this increased freedom allows for the creation of optimum musical instruments for sound quality, playing ability, ease of construction, increased range of tones at an increased range of size, as well as increased economy, and structural beauty.

xiii) The functional definition for Tensegrity, given in section “c part viii” on page 10 and in section “k” on page 19, allows the addition redundant tensile elements for purposes such as increased rigidity or mode suppression on a chime. This functional definition also allows for removal of a tensile element for the purpose of making a hanging Tensegrity which is collapsible when it is taken down. The creation of musical instruments taught in this invention are a retyping of a class of Tensegrities. These Tensegrities are defined specifically by the definition given in section “c part viii” on page 10 and in section k on page 19 of this document. The definition defined there specifically does not require or preclude the tensional elements of said Tensegrities.
from being continuous. It also does not require or preclude, bending, shear, torsional, strains on the struts, as the less general definition of Tensegrities given by Kenneth Snelson does.

An excellent example of Tensegrity is shown in Snelson’s Needle Tower (FIG. 21), which as mentioned before, is permanently exhibited in the at the Smithsonian in Washington D.C. This tower, consisting of progressively smaller aluminum tubes tied apart with stainless steel cables so it rises 60 feet into the air. The struts seem to “float” in a sea of tensioning cables. In addition to showing what Tensegrity is, some of the benefits of the use of Tensegrity are illustrated. Here when the tower is loaded, for example in a high wind, or by attaching a rope to its top and attempting to pull it down, the whole tower will yield and absorb the incident stress which is distributed or communicated over the whole structure by the set of tensional elements, so that buckling associated with a rigid conventionally built tower is avoided. Said another way; attach a rope to the top of a conventional tower, of the same height, and pull as the Needle Tower, and pull with a force “F” until the tower buckles and collapses. Next attach the rope in the same manner to the needle tower and pull with the same force “F” and observe that no buckling occurs. Instead the tower yields and the bulk of the stress applied to the top of the structure is effectively spread to all of its elements in with out damage to any of those elements. When the stress is removed the tower simply resumes its original unstressed position. The distribution of the stress through throughout the whole Needle Tower is communicated through the tensional elements. Thereby illustrating how the tensional elements act in a continuous manner even when they are composed of discrete elements. This is a key property of Tensegrity structures. Another key Tensegrity property demonstrated with the Needle Tower is Flexibility. The tower like a weed in the wind returns to its original position undamaged after the storm has passed. Even this gigantic sculpture would become a percussion musical instrument if its strut ends were extended past respective tie points, such that tie points become the nodal points of the fundamental mode of each of the struts. This conversion could literally take place by welding on the appropriate length extension tubes to the ends of all of the struts that are to become resonators.

The father of Tensegrity, Kenneth Snelson, now defines them as: “Tensegrity describes a closed structural system composed of a set of three or more elongate compression struts within a network of tension tendons, the combined parts mutually supportive in such a way that the struts do not touch another, but press outwardly against nodal points in the tension network to form a firm, triangulated, prestressed, tension and compression unit”

Because Tensegrity represents a new, unfamiliar, and uniquely defined class of structures that mimics nature they have been, and to some extent still are, misunderstood by the general public. Also in the course of his work Buckminster Fuller. Commingled some of his previous work with Snelson’s original structural idea adding further to the confusion of what is meant by Tensegrity. This ongoing misunderstanding has led, overtime, to a loss of rigor to the word “Tensegrity”, as it began to be applied to music scores, thought systems, personal relationships, exercise regimes and so on.

It is instructive to look at the original Tensegrity structure built by Snelson in 1948 and displayed by Buckminster Fuller in 1949. A drawing of a model of this “Tensegrity Icosahedron” is shown in (FIG. 1). Some of the features and benefits seen here are the same as we saw in the Needle Tower: 1) the struts are supported by the tensile elements so they do not touch each other. 2) When a stress is applied to any of the elements that element is displaced and the wires holding it in place transmit the bulk of the applied stress to the other components of the structure.

Some pneumatic examples of everyday Tensegrities are the balloon and the automobile tire. Here the stretched elastic skin of the balloon and the expanded rubber tire shell represent the continuous tensional element, where as, the discrete compression elements are represented by the air molecules contained inside the balloon and tire. These pneumatic examples are a far stretch from Snelson’s original definition since the tensional elements are not connected to said compression elements. This is an example of what has happened to Snelson’s original idea of Tensegrity. Furthermore, since there are no actual struts in these so called “pneumatic Tensegrities” they can not be included in the definition of Tensegrities that can be made into musical instruments as taught by this invention.

As a result of indiscriminate use, the meaning of the word Tensegrity has become increasingly vague. Since its inception the meaning of Tensegrity has expanded to cover everything from bicycle wheels, to anything that uses tension as one of its main structural components, to the harmonious give and take in the relationship between a student and teacher, to a description of a certain type of music, to a description of nature itself.

For clarity in the description of the present invention. The scope of the word Tensegrity will be narrowed to: “physical structures consisting of rigid, or semi-rigid, struts of arbitrary shape and material suspended in a network of tensional elements, also of
arbitrary shape and material, so the struts stand apart from one another. In other words, the definition of Tensegrity is: “struts tied together at two or more point such that the struts are held apart either firmly or flaccidly apart, with or without the use of gravity”. The struts are held in a network of tensile element such that the struts don’t touch each other. This definition of Tensegrity now more closely resembles the original definition of Tensegrity based on Snelson’s sculptures, and includes them as a subset. This definition also includes hanging Tensegrities where one or more of the Tensile elements of a Snelson Tensegrity have been removed so that the “semi-Tensegrity” so formed, falls apart as the struts come together when the Tensegrity is not hanging. When hanging the forces previously provided by the missing tensile elements is supplied by gravity It notably does not include, pneumatic Tensegrities such as balloons and automobile tires, as well any kind of strut and tensional element as long as the struts support the compressive loads built into Tensegrities, and the tensional elements can take the tensile forces built into Tensegrities. The definition specifically does not limit Tensegrity struts to compressive strains. The struts can have any and all combinations of compressive, bending, torsional, and/or shear strain when loaded by the Tensegrity assembly.

[0061] i) The definition does not limit in any fashion the shape or composition of the struts. They could be glass spheres, bamboo hula hoops, or ceramic coffee cups, or be of abstract geometric 2d or 3d shapes such as flat triangular, square, pentagon, or completely arbitrarily shaped plates, or solid cubes, pyramids, tetrahedrons, rods, tubes, rectangular solids, asteroid shape, or of any other shape including completely arbitrary ones. Further more the plates and solids could be modified with arbitrary features such as holes, serrations, or extrusions, of any kind on them. Also the struts can be semi-rigid as well as rigid. This would among other things allow the struts to deform under the stress from the tensile elements. The definitional also allows redundant tensional elements not actually required for the struts to stand apart.

[0062] m) Likewise the tensional elements could be of any material and shape including but not excluding anything else: rubber sheets, canvas tarps, Kevlar straps, metal or wood chain, or carbon fiber cable.

[0063] n) The struts and tensional elements can be any shape or materials. However, the struts are generally metal or wood, rods or tubes, and the tensile elements are generally rope, cable, or wire.

[0064] o) A Tensegrity structure consists of a set of ridged struts, suspended in a network of tensional elements, where the tensional elements tie the struts tightly together, in such a way that the struts stand forcibly apart.

[0065] p) As mentioned before, looking at physical Tensegrity structures is one of the best ways to gain insight into what Tensegrity is. Lets examine the simplest type of Tensegrities I call “twisted prisms” the class which forms the preferred embodiment of this invention. The simplest “twisted prism” (FIG. 2) requires three struts, has 3-fold symmetry, and is built in a way such that its complexity can be increased by adding any number of struts to the structure connected in the same manner the original three were. A five strut “twisted prism” exhibits 5-fold symmetry and is shown (FIG. 6).

[0066] q) To convert “twisted prism” Tensegrities into “Tensegrity Chimes” the tension element ti points are simply moved in from the strut ends to two of the of the nodal minima’s of one of the struts free beam resonant modes. The figures (FIG. 7) & (FIG. 8), show a 3-fold symmetry version of the “twisted prism”, while figures (FIG. 9) & (FIG. 10) show a version with 5-fold symmetry. In the examples above the fundamental mode is selected. In a similar manner the 2nd, 3rd, 4th, 5th and so on, overtones could have been selected by simply tying the Tensegrity struts at their respective nodal points. In the case of the overtones above the fundamental more than a single set of nodes are possible. Accordingly any two of the nodes could be used to attach the resonant strut to the Tensegrity. Also as described earlier, any number of redundant tying to the other nodal minimums can be employed for the variety of reasons mentioned earlier.

[0067] r) Snelson favored calling his Tensegrities by the more descriptive name “floating compression” structures, which gives one a mental image of the structures themselves. For example look again at the Snelson’s needle tower sculpture (FIG. 21) and the twisted prism examples (FIG. 2) and (FIG. 6): all of these consist of three or more struts in compression held tightly together in a network of wires, in such a way that the struts stand forcibly apart from one another. That is, the compression struts seem to float in a network of tensional elements, and thus the name “floating compression”. This effect is even more pronounced when the number of elements becomes large. Look at the Tensegrity sphere (FIG. 11), and noticed that the multitude of compression struts seem to be literally floating in a sea of high-tension wires.

[0068] s) The Tensegrity Musical Instruments described in this patent are Tensegrity structures as defined above in sections k) through m), and are generally the Snelson “Floating Compression” type Tensegrities.

[0069] t) Now for an idea of how a Tensegrity construction works, look once more at (FIG. 2) the “twisted prism” the simplest Tensegrity structure. This structure has three struts and nine “tensional members” which are sometimes called “tendons”. The tendons are numbered one through nine, are the struts are numbered one through three in roman numerals. Notice that tensional elements 1, 2, 3 form a triangle which tie the top of the struts together, and that in the same manner tensional elements 4, 5, 6, form a triangle which tie the bottom of the struts together. If the struts are now held vertical a regular right triangular prism is formed; where the three struts and six tensional elements define the edges. Now imagine an axis “Z” through the center of the bottom and top equilateral triangles formed by the tensile elements. Next imagine that the bottom triangle is held fixed while the top triangle is “twisted” counter clockwise (viewed from the top) about the “Z” axis through 150 degrees while remaining parallel to the
bottom triangle. At this point the top of strut I will be nearly directly over the bottom of strut II, and the top of strut II will be over the bottom of strut III, and completing the symmetric loop strut III will be over the bottom of strut I. Now as it works out the distance between these symmetric top strut bottom strut pairs is a local minimum. This means if the angle of the top triangle is rotated with respect to the bottom triangle either clockwise or counter-clockwise the distance will increase. Therefore as tendons 7, 8, & 9 are tied between these top-strut/bottom-strut pairs the struts and strings will form a rigid structure. This structure is called a Tensegrity. In an analogous manner the 5-fold “twisted prism” shown in (FIG. 6) can be created. In general any n-fold “twisted prism”, where n is any integer three or greater, can be created.

[0070] u) Look again at the Needle Tower (FIG. 21) for a more elegant example of a Tensegrity structure, which posses a more complex symmetry. The 60 foot tall “Needle Tower” is displayed in the sculpture garden just outside the Hirshhorn gallery in Washington D.C.’s Smithsonian.

[0071] v) See (FIG. 3) for a variation on the typical cube Tensegrity (FIG. 20). Here a cube is shown that consists of long struts that form the edges of the cube, and which run between vertices that consist of localized “Tensegrity Joints”. This cube is also a Tensegrity since it, as mentioned earlier, fits our working definition of Tensegrity, and since it can be converted to a musical instrument in the same manner as the “twisted prisms” have been in (FIG. 7), (FIG. 8), (FIG. 9), and (FIG. 10). In both the Tensegrity cube and the particular rigging of 3-fold & 5-fold “twisted prism” Tensegrity Musical Chimes illustrated in (FIG. 7), (FIG. 8), and (FIG. 9), notice that the tensional elements are not continuous, but are rather only piecewise continuous. In the case of the Tensegrity cube (FIG. 3) each “Tensegrity Joint” has a continuous tensional element located in the eight corners of the cube, which are discontinuous with each other. Here the cube’s tensional elements are not only physically discontinuous they are functionally discontinuous in that some of the stress sharing properties associated with a Tensegrity are lost. However in the case of the particular Tensegrity Musical Chimes just mentioned, the tensile elements are physically disconnected yet are functionally continuous, in that the Tensegrity behaves the same as if the tensile elements were physically connected.

2) Now that we have discussed what a Tensegrity is, and cleared away some of the ambiguities surrounding Tensegrity, as well as established a working definition for the Tensegrity nature of the musical inventions this patent teaches how to create, we will turn to establishing a working functional definition of what a musical instrument is.

[0072] a) In principle a musical instrument can be described, to first order, as a set of resonating elements, a method to excite the resonators, and a method to couple that resonate energy into the air so the ear can appreciate it.

[0073] b) A first order, functional description of a musical instrument is a set of resonating elements, a method to excite the resonators and a method to couple that resonate energy into the air so the ear can appreciate it.

[0074] c) Put another way: a musical instrument is a set of “resonators” or “resonating elements” such as strings of a piano, the hollow tube of a trumpet, or the flat metal bars of a Xylophone, whose modes can be excited with an “exciter”, such as a hammer, bow, or finger tip, and whose resonate energy can be extracted into the air by a “coupling transducer”, such as the bell of a horn, the sounding board of a piano, or the bridge and ported sounding box of a violin, so that it be heard by an ear in the vicinity of the resonator.

[0075] d) Sometimes the “coupling transducer” is an integral part of the resonator and not a physically separate part, such as the bell shape on the end of a horn, the edge of a symbol, or the open end of hollow bamboo stick, other times, and more commonly, it is a separate set of parts such as the bridge and ported sound box of a cello, banjo, or bass, or the magnetic pickup, amplifier, and speaker of an electric guitar. In the Tensegrity musical instrument invented and described in this patent the resonators have an integral “coupling transducer” much like that of the hollow bamboo stick.

[0076] e) Examples of the “resonators”, “exciters”, and “coupling transducers” of common musical instruments:

[0077] i) In a piano the strings are the resonating elements, the hammers excite the strings and the sounding board serves to couple the energy of the resonators to the air.

[0078] ii) In a trumpet the air column contained within the length of the horn, which forms a tube open on one end and closed on the other, is the resonating element. The vibrating lips of the person playing the trumpet serve to excite the resonator, and the exponential bell shaped opening is the “coupling transducer” which couples the resonating column of air to the air outside the tube by matching the impedance of the air within the tube to that of the surrounding free air.

[0079] iii) In an acoustic guitar the strings form the resonating elements as they did in the piano, the fingers or picks of the guitar player excite the resonators as they are plucked, and the bridge, and ported hollow guitar body and body surface is the “coupling transducer” which couples energy from the resonating strings to the free air so it can be heard effectively by the listeners ear.

[0080] iv) In a simple Xylophone like instruments the “coupling transducers” are an integral part of the resonator and do not require any external parts. The ends of the resonators themselves are the transducers. This is distinct from more elaborate Xylophones like instruments, which like the Marimba, have an output coupling tube, which placed close to the middle of each resonator to couple its resonate energy in to the free air. The output coupling tube is the “coupling transducer”.

[0081] f) The Tensegrity musical instruments described later in this patent, like the xylophone use the surface of the resonators themselves for “coupling transducers”.
The resonators for Xylophone-like instruments come in many forms. When the resonators are flat metal bars, the instrument is called a Xylophone. However, many other resonators are commonly used in this type of instrument, such as wood flat bars, hollow metal or wood tubes, bamboo sticks, or plastic or glass rods.

These Xylophone-like instruments consist of a set of resonating chimes whose fundamental mode is free to be excited when the chime is held at the two nodal points about 22.4% of its length in from each end. When the resonating bars/tubes are held at these nodes, the ends of the chime are free to flap in the air (see FIG. 15A). FIG. 15 illustrates the fundamental mode FIG. 15A, the second overtone FIG. 15B, and the third overtone FIG. 15C. The free resonances of a beam create the overtones which come about due to reinforcing reflections off the beams ends. The fundamental resonance comes about when the round trip phase difference is 360 degree’s, and overtones come at integer multiples of 360 degree’s. The second overtone is at 2 x 360 degree’s and the third overtone is at 3 x 360 degree’s and so on. Due to the complex nature of sound traveling in a solid the overtones are non harmonic and none of the nodal minimas points for any of the overtones are coincident. The non harmonic overtones sound discordant and the chimes can make a clanking sound when struck. The “exciter” is a hammer, which the musician strikes the resonator with. Unlike most of the previously described instruments, the coupling mechanism for the Xylophone chime is contained within the chime itself. Here the chime is held or supported at the two internal modes so as to force the ends of the chime to nodal maxima’s. The majority of the resonator energy is coupled to the air and is now coupled at the chime’s three nodal maxima’s located at the center and two free ends of the chime, where the resonator has maximum velocity and displacement.

What is a Tensegrity Musical Instrument?

Most Tensegrity structures can be tied so that they become musical instruments. A simple retying of the struts so that the tensional elements tie points are moved into one of nodal minima’s of a desired free beam resonant mode. The simplest and most common mode is the fundamental mode that is one wavelength long and has two nodal minima located about ¼ wavelength from each of the strut’s ends. Here a musical instrument is created by moving the tie points of the tensional elements in from the end points to the two nodal minima on the strut. Compare (FIG. 2) with (FIG. 8) and see the transformation of the three strut twisted prism into a 3-resonator chime. A pleasing sounding chime can be made by choosing the three lengths to be different and so they form a major cord such as C, E, & G, or an intriguing sound can be made by choosing the lengths so they form a minor cord. Other variations such as cross coupling between the resonators can be created so that when one chime in the set, say one tuned to C, the other elements in the chime, say E, & G, are sounded. This cross coupling can be controlled physically in many ways. One of the ways is to designing the chime set so that the tensile elements that normally only touch the struts where they attach at the nodal minima’s, touch at other points along the strut and thereby utilize the Tensegrity nature of the chime to tug on adjacent elements when stressed to couple energy from one resonator to the next. The procedure just described is a part of what this invention teaches.

A Tensegrity Musical Instrument is a Tensegrity structure where one or more of the strut members becomes a Tensegrity chime by tying it to the rest of the Tensegrity, "floating compression" structure by insisting that the two tie points be at natural nodal minima’s of the free beam resonance mode that is desired see (FIG. 16). In most cases, and as done in the preferred embodiment of the Tensegrity Musical Instruments of the present invention, all of the struts are tied to each other such that all of the struts in the structure become Tensegrity Musical Chimes. Also, in most cases the struts are tied at two of the nodal minima points as in the preferred embodiment of this invention. However the struts can be tied at tied at each of the free beam resonance nodal minima. In so doing a strut may be tied in 3, 4, 5 places as long as all of those places are nodal minima’s for the desired resonant mode, such as shown in (FIG. 4A).

A Tensegrity Musical instrument is a Tensegrity structure where the junctions which separate the discrete struts with discrete tensional elements or defined to be only at the internal nodal minima’s of the resonate modes chosen for that strut.

Where the struts of a Tensegrity structure are held only at nodal minima such that the high Q of at least one of the free resonances are retained, and such that the strut resonant energy can be coupled effectively into the surrounding air to be appreciated by a nearby ear.

Where specifically, the traditional Tensegrity structure struts, which usually are rods or hollow tubes, are not to be held at their ends as they typically are. If these struts are held at their ends all of the free beam resonant modes of the strut are destroyed as the beam ends are forced to become nodal minima’s at the strut ends, where as the free beam resonance of the strut is required to have a nodal maxima at the beam end. In addition to destroying the Q of the resonators which renders them unable store the energy of the musical tones, tying these struts at their end points eliminates the previously described integral “coupling transducer” preventing the strut end from coupling the struts resonate energy into the surrounding air. The new boundary conditions that restrict the movements of the end of the beam by tying the tensional elements at the beam end simultaneously kill the free beam resonances, and prevents energy stored in the beam from coupling into the air. In addition to killing the free beam resonances of the strut and destroying the tubes natural built in “coupling transducer” the tensional elements do not hold the ends of the beam firmly enough to create the new resonance modes that would be created if the beams were held rigidly in place. The Q of these potential new modes is depressingly low since the ends move slightly coupling the energy into lossy modes of the tensional elements.
4) Additional Detailed Description

a) Describe the general case of Tensegrity structures into Tensegrity chimes: In general, most know Tensegrity structures can be retied at their free beam resonant nodal minima’s and thereby be converted to a Tensegrity musical instrument. The present invention teaches that a Tensegrity musical instrument is created by moving the tie point of most known Tensegrities, and new yet to be created Tensegrities, from the strut ends (or wherever they are initially tied) to the free beam nodal minima points on the strut for the resonance mode desired.

b) The “twisted prism” subset Tensegrity Musical Instruments described earlier are preferred embodiments of this invention.

c) Some of these preferred embodiments are illustrated by the following 3-fold and 5-fold Tensegrity Musical Instruments:

i) (FIG. 12) shows a 3-Note Desk Chime

ii) (FIG. 13) illustrates a 5-Note Desk Chime

iii) (FIG. 14) shows a 3-Note Wind Chime

iv) (FIG. 17) illustrates a 5-Note Wind Chime

d) The structure that forms the 3-Note Chime and 5-Note Chime Are “twisted prism” Tensegrities, that can be generalized into and n-Note Chime with n resonating struts.

e) The Free beam strut resonant modes with associated nodal minima and maxima points are shown in (FIG. 15A), (FIG. 15B), (FIG. 15C), & (FIG. 15D).

If a chime is held by elastic wires in tension anywhere other than one of its free beam resonant nodal minima’s it will not ring when struck with a hammer, because the free beam resonances are damped severely or not allowed depending on how far off the nodal minima’s and how firmly the struts are held. In addition, the wires do not hold the strut firmly enough to set up a new set of resonances defined by the beam holding points. Instead the energy induced in the strut by the hammer strike is mostly lost to the holding wires. It is simply carried away and dissipated as heat or acoustic radiation. Note that for any given free beam mode to exist after it is tied into a Tensegrity that the tie points must all be on one of the nodal minima’s for that mode. Notice that none of the free beam resonances have nodal minima at either end of the strut. In fact just the opposite is true. All of the free beam resonances have nodal maxima’s at the ends. Therefore all of the free beam resonances are thoroughly sniffed out once the strut is tied into a Tensegrity in the traditional manner by attaching tensile elements to both of its end points.

f) As you can see from the description just given of allowed strut resonances, that many of the free beam resonances have different nodal minima points. So when the nodal points to tie to are chosen all of the modes which do not have nodal minima’s there are filtered out. This permits the Tensegrity Musical Instrument creator the freedom to choose which free beam resonator modes to preserve by which nodal minima’s the musician can further modulate which of the modes are sounded when the chime is struck by choosing where to hit the chime and thereby which of the allowed modes are excited.

b) A dual mode Chime can be created to get two tones or notes from one chime by choosing chime of a rectangular cross-section in this way twice as many notes can be obtained on a chime unit. For example a 4-chime set will now have 8 notes instead of 4. This creates a whole 8-note scale (do, ray, me, fa, so, la, te do) with only 4 dual mode chimes. The resonant modes in a chime are formed by transverse mode traveling waves that form resonant modes due to the finite length of the chime tubes. The ends of the tubes form the boundaries that the traveling waves reflect from, and these wave reflections reinforcing the incident waves cause standing waves to form on the tubes with nodal minima’s and nodal maximum’s. The fundamental free beam transverse resonance mode for the chime occurs when it is one wavelength long acoustically. That is when the round trip phase change of a wave going from one end to the other, and back again to the original end is 360 degrees. This mode contains three nodal maxima’s and two nodal minima’s. The maximum’s are at both ends and at half the length of the chime (in the middle), whereas the minima’s are approximately a quarter wave in from each end. If the fundamental mode is desired then the chime is tied at these nodal minima’s. It is important to note that the nodal minima’s for the dual mode chimes described here are at the same point for both modes. This means that when chime is tied into a Tensegrity structure at these nodal minima’s both notes are allowed.

i) Two orthogonal transverse waves can be supported on a single rod or tube. Usually both of these modes travel at the same velocity due to the radial symmetry of the tube. However if a non-square rectangular or an oval tube is used for the chime the velocities on the longer transverse axis Labeled “X” in (FIG. 19) moves faster that the shorter transverse axis labeled “y” as the traveling wave moves in the “z” direction. The reason for the speed difference is that the velocity “V” is proportional to the stiffness “S” divided by the linear density “D”. (V=S/D). That is to say the velocity is directly proportional to the stiffness. Also the frequency “F” of resonance of the tube is directly proportional to the velocity “V” and inversely proportional to the length of the tube “L”. Therefore the Frequency “F” is directly proportional to the Stiffness “S”. Further more the stiffness “S” goes up with the cube of the thickness “T”. Putting this altogether means the two orthogonal modes which now have different thicknesses travel at different velocities and have different fundamental resonant frequencies due to the increased stiffness of in the “x” direction compared to the “y” direction of the cross-section of the chime. Further more each note can be excited with independently or both notes can be excited simultaneously. If the chime is hit with a hammer in the stiffer “x” direction the higher note will sound, and if hit the “y” direction the lower note will sound. Also both notes can
be made to sound simultaneously with a single hammer stroke at 45 degrees from the “X” axis. Still more interesting is that the relative amplitude of each note, one to the other, can be controlled by the strike angle. In the hands of a skilled percussionist a single dual mode chime invented here can make a whole range of sounds with varying amplitudes of the chimes two fundamentals and many harmonics. Also if the cross-section of the tube is designed so that it is only slightly asymmetrical (i.e. slightly oval or slightly off square), then rich sounding phasing of the two tones occur adding a fullness to the chime sound. This fuller sound is often desired in musical instruments.

What is claimed is:

1) Method of converting any tensegrity structure into a musical instrument where one or more of the struts become the resonating elements by tying the struts together at any one or more internal strut nodal minimum of the desired resonant mode for that strut.

2) The method of claim 1, where the Tensegrity being converted into a musical instrument is a “twisted prism”. Where the number of struts n can be any integer three or greater.

3) Multi-mode resonating chimes created from one or more of a Tenseгрities’ struts by choosing the strut to be any shape or combination of shapes, and or material or combinations of materials to create desired multi-modal resonance in Tenseгрity struts.

4) Chime described in claim 3, where the strut is a solid rod or hollow tube with one or more distinct radial symmetries and or asymmetries.

5) Chime described in claim 3, where the strut is a solid rod or a hollow tube with one or more distinct longitudinal symmetries and or asymmetries. Longitudinal symmetries have variations on long the length of the strut, and can include changes in shape, materials, or properties of the material such as thickness and or density.

6) Chime described in claims 3, 4, & 5, where chime is of triangular, and or different cross-sections including symmetric and or asymmetric rotational modulations with and without symmetric and asymmetric radial variations thereof. For example, one such variation with 5-fold rotational symmetry would form a five-pointed star cross-section whose points are of different lengths and base widths.

7) Chime described in claims 3, 4, & 5, is of rectangular, and or different cross-sections including symmetric and or asymmetric rotational modulations with and without symmetric and asymmetric radial variations thereof.

8) Chime described in claims 3, 4, & 5, is of an oval, and or different cross-sections including symmetric and or asymmetric rotational modulations with and without symmetric and asymmetric radial variations thereof.

9) Chime described in claim 3, 4, & 5, where the asymmetry is designed to be nearly the same so as to create a rich sounding phasing of two or more tones created making fullness in the sound that is often desired of musical instruments by musicians.

10) Chime described in claim 3, 4, & 5, where the asymmetry in cross-section is set to provide a particular frequency offset of the one or more tones created, such as a 2nd, 3rd, 4th, 5th, 6th, 7th, a full octave, or any other frequency offset desired.

11) Any single or multi-modal chime described in claim 3, made of metal, wood, plastic, glass, ceramic, and/or any other materials or combinations thereof.

12) Any single or multi-modal chime described in claim 3, of a rectangular, oval triangular, and any other shape, size, or cross-section where each variation, including longitudinal variations, can be realized singularly, or in any combination thereof.

13) A method where desired cross coupling of the resonators in a multi-resonator Tenseгрity is accomplished by exploiting the Tenseгрities struts inherent ability to share an applied stress with the struts adjacent to it.

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