

A STRUCTURE AND METHOD OF FORMING A STRUCTURE

FIELD OF INVENTION

[001] The present invention relates broadly, but not exclusively, to a structure and to a method of forming a structure.

BACKGROUND

[002] Structural integrity is important for buildings and architecture. Building structures that bear loads through compression, which is the guiding design principle of most buildings today, use members that are bulky and require increased amounts of material because structural performance under compression is dependent on member thickness or cross-sectional area. Typically, steel and concrete are used for the construction of buildings because these materials are deemed to be able to support loads. However, the present paradigm of massive buildings dominated by steel and concrete is fading for a preference of elegant, minimalist architecture that has less negative impact on the environment and simplifies the construction process. Consequently, there has been a surge of interest in the exploration of textile membrane structures.

[003] Membrane structures are reputed for their ability to span wide spaces while remaining incredibly thin, on the scale of tenths of millimeters, as tension-only shell structures. Although the textile itself is lightweight, these textile membrane structures typically utilize a complicated external support apparatus to tether and shape the membrane, resolve its live loads, and apply sufficient amounts of pretension to keep it taut and stiff. Dissolving this technical, aesthetic, and conceptual dichotomy of pairing an airy, thin membrane with a substantial support system is a current challenge that, once overcome, can potentially catalyze widespread adoption of lightweight, environmentally-friendly textile membrane structures.

[004] A need therefore exists to provide a structure that seeks to address at least some of the above problems.

SUMMARY

[005] According to a first aspect, there is provided a structure comprising: a membrane with tensile properties; and a plurality of reciprocal patterning units disposed within the membrane, wherein each reciprocal patterning unit comprises a plurality of struts and wherein each of the plurality of struts are configured to provide tension forces in a plurality of opposing directions to an area of the membrane in each reciprocal patterning unit, wherein the membrane exerts compression forces on each of the plurality of struts, and wherein each of the plurality of struts exert the tension forces on the membrane simultaneously to maintain structural integrity of the structure.

[006] According to a second aspect, there is provided a method of forming a structure, comprising the steps of: providing a membrane with tensile properties; and disposing a plurality of reciprocal patterning units within the membrane, wherein each reciprocal patterning unit comprises a plurality of struts and wherein each of the plurality of struts are configured to provide tension forces in a plurality of opposing directions to an area of the membrane in each reciprocal patterning unit, wherein the membrane exerts compression forces on each of the plurality of struts, and wherein each of the plurality of struts exert the tension forces on the membrane simultaneously to maintain structural integrity of the structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] Embodiments and implementations are provided by way of example only, and will be better understood and readily apparent to one of ordinary skill in the art from the following written description, read in conjunction with the drawings, in which:

[008] Figure 1 is a digital model of a freeform membrane tensegrity shell structure, according to an example embodiment.

[009] Figure 2, comprising Figures 2(a) and 2(b), is a schematic representation of a strut in different shapes, according to example embodiments.

[0010] Figure 3, comprising Figures 3(a) to 3(f), is a schematic representation of a reciprocal patterning unit made up of the struts of Figure 2.

[0011] Figure 4, comprising Figures 4(a) to 4(j), shows example steps of generating reciprocal patterns using the struts of Figure 2.

[0012] Figure 5 is a schematic representation of a reciprocal pattern, according to another example embodiment.

[0013] Figure 6 is a flowchart illustrating a method of forming a structure, according to an example embodiment.

DETAILED DESCRIPTION

[0014] Embodiments will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

[0015] The present disclosure may relate to structural design of textile structures in the disciplines of architecture and building structures.

[0016] One possible solution to the challenge described above is creating textile structures that do not require any extensive support apparatus. One possible approach for achieving a self-supporting structure is by using a tensegritic structural system. Tensegrity (tensile integrity) structures, as the name suggests, are tension-dominated, self-supporting structures that comprise minimal, discontinuous (non-touching) compression elements connected by an array of continuous tensile elements. As mentioned above, building structures that bear loads through compression typically use members that are bulky and require increased amounts of material. Tensegrity structures, as tension-dominant structures, are a provocation to this status quo: the compressive elements are diminished in size and mass to such an extent that they serve solely as a means of pretensioning and transferring loads to thin tensile elements. For this reason, tensegrity structures can be excellent in terms of their material efficiency. Furthermore, and in contrast to the typical image of a building being uncompromisingly static and rigid, tensegrity structures can be flexible and robust. In addition, tensegrity structures are able to achieve stable equilibrium in many different configurations due to the carefully organized relationship between the compressive and tensile elements.

[0017] In some prior art tensegrity structures, the compression elements take the form of struts or rods, whereas the tension elements are manifested by cables. However, using slender, one-dimensional tensile elements may provide an inherent difficulty in creating spatial, programmatic architectural situations using tensegrity principles. One possible solution may be to incorporate textile membranes in tensegrity. Membranes, which can be taken to be wide-spanning, two-dimensional version of cables, may fulfill the role of tensile elements to enable the creation of shell-like membrane architecture that does not require any external pretensioning support structure, as per the self-supporting principles of tensegrity.

[0018] In the present disclosure, fundamental units of reciprocal patterns of compressive struts have been developed such that, once embedded in an elastic tensile membrane, it allows for the creation of self-supporting, lightweight membrane tensegrity shell structures of a variety of open 3D forms. Consequently, it is possible to simultaneously shape and stiffen the membrane into a free-standing, load-bearing spatial structure. The present disclosure may instill strut configurations that are more effective in achieving the stiffness required for the membrane to maintain structural integrity without being tethered to any external supports, while still allowing for programmatic architectural features such as openings. It would be appreciated that strut configurations include both the shape and size of the strut as well as the pattern of strut placement in the plane of the membrane. The reciprocal patterning units may serve to distribute the pretension in a redundant fashion so that the tension elements are sufficiently prestressed so as to effectively bear loads.

[0019] Figure 1 is a digital model of a freeform membrane tensegrity shell structure 100, according to an example embodiment. Struts in cross shapes 102 are embedded in an elastic tensile membrane 104 to form a self-supporting membrane tensegrity structure 100 that can be in the form of various shapes.

[0020] The present disclosure provides strut configuration principles that enable structural performance of the membrane. Figure 2, comprising Figures 2(a) and 2(b), is a schematic representation 200 of a strut in different shapes, according to example embodiments. Figure 2(a) shows a strut in cross shape and Figure 2(b) shows a strut in asterisk shape.

[0021] In typical tensegritic systems, the struts serve to span, apply pretension to, and transfer loads between the tensile elements. In the present disclosure, the fibers that make up the membrane are the tensile elements. A tensegritic structural system can successfully bear loads with geometrical arrangements (i.e. size, spacing, and orientation) of struts and tensile elements where the tensile elements are highly pretensioned and directed along the lines of force. Membrane tensegrity using cross and asterisk struts can be used due to their ability to generate pretension in an increased number of areas of the membrane (i.e. an increased number of strut ends) while still allowing ease of fabrication. Any suitable strut configuration may comprise struts having one center point from which an even number of compressive members (e.g. 4, 6, 8, 10, etc.) extend therefrom. For example, as shown in Figure 2(a), struts in cross shapes are a group of struts having one center point from which four compressive members extend at perpendicular angles respective of one another. Another example is as shown in Figure 2(b). Struts in asterisk shapes are struts having one center point from which six compressive members extend at about 60° angles respective of one another. Struts in asterisk shapes can generate pretension in more areas due to the increased number of strut ends. However, connecting three struts together involves one more step than connecting two. Thus, the associative relationships between assembly time, strut type, and number of struts needed to generate sufficient pretension may need to be considered when deciding on strut configuration.

[0022] The struts can be placed within the plane of the membrane and arranged in a 2D fashion, assuming the membrane is in its flat state. The highest pretension is experienced by the parts of the membrane nearest to each of the strut ends and decreases for parts of the membrane farther from the strut ends. However, in order to have smooth, shell-like membrane curvature and taut stiffness, the pretension is preferably both high and evenly distributed. As such, spacing between the strut ends should be organized in such a way that pretension uniformity can be achieved. Spacing can be determined by three parameters: strut length, strut rotation angle, and strut location. The optimal combination of these parameters for the desired uniform pretension distribution can be resolved using reciprocal patterning method. The reciprocal strut patterns, being inherently self-similar and posing at least one degree of symmetry (either translational or rotational), may bring forth redundancy in the directions that the membrane fibers are being pulled throughout the structure. The desired pretension amount of the membrane, in turn, can be achieved via the interplay between the reciprocal patterning and the textile's tensile properties.

[0023] Embodiments of the invention provide fundamental reciprocal patterning unit for cross and asterisk struts layered upon a section of membrane. Figure 3, comprising Figures 3(a) to 3(f), is a schematic representation 300 of a reciprocal patterning unit 310a, 310b made up of the struts of Figure 2. Figures 3(a) to 3(c) show reciprocal patterning unit 310a made up of struts in cross shapes 304a while Figures 3(d) to 3(f) show reciprocal patterning unit 310b made up of struts in asterisk shapes 304b. The reciprocity is emphasized in Figures 3(b) and 3(e) and the valence polygons 308a, 308b are shown in Figures 3(c) and 3(f).

[0024] According to an embodiment of the invention, there is provided a structure comprising a membrane 302 with tensile properties and a plurality of reciprocal patterning units 310a, 310b disposed within the membrane 302. Each reciprocal patterning unit 310a, 310b comprises a plurality of struts 304a, 304b and each of the plurality of struts 304a, 304b are configured to provide tension forces in a plurality of opposing directions to an area of the membrane 306a, 306b in each reciprocal patterning unit 310a, 310b. Further, the membrane 302 exerts compression forces on each of the plurality of struts 304a, 304b, and each of the plurality of struts 304a, 304b exert the tension forces on the membrane 302 simultaneously to maintain structural integrity of the structure. The plurality of opposing directions may comprise four or more opposing directions. The plurality of struts may be configured as cross shapes 304a or asterisk shapes 304b. The redundant overlap can subject the part of the membrane centered in the fundamental unit to a high amount of pretension in different opposing directions, thus enabling stiffening of the textile membrane.

[0025] In an implementation, each reciprocal patterning unit 310a, 310b exhibits at least one degree of symmetry. The at least one degree of symmetry may comprise translational symmetry or rotational symmetry.

[0026] The reciprocal nature of the patterning units 310a, 310b can be defined by valence polygons 308a, 308b, such as triangles 308b and parallelograms 308a, which can be drawn by connecting the endpoints of the reciprocally patterned struts 304a, 304b as shown in Figures 3(c) and 3(f).

[0027] In another implementation, the area of the membrane 306a, 306b in each reciprocal patterning unit 310a, 310b comprises endpoints of the plurality of struts 304a, 304b. Further, the endpoints of each of the plurality of struts 304a, 304b are

configured to define an area corresponding to a polygon 308a, 308b comprising three or more edges. It would be appreciated that the polygon 308a, 308b can also be of any number of edges and of any size.

[0028] Figure 4, comprising Figures 4(a) to 4(j), shows example steps of generating reciprocal patterns using the struts of Figure 2. Figures 4(a) to 4(e) show steps of generating reciprocal patterns using the struts in cross shapes while Figures 4(f) to 4(j) show steps of generating reciprocal patterns using the struts in asterisk shapes. Aggregations of units of reciprocal struts can be designed by drawing sets of overlapping (and in the case of asterisks, staggered) geometric tiles, as shown in Figures 4(a) and 4(f). The diagonals of the tiles can be populated by the struts, as shown in Figures 4(b) and 4(g). The tiles may then be rotated so that the struts do not touch and the empty areas between the struts are in closer proximity to strut ends, as shown in Figures 4(c) and 4(h), to induce multiple pretension directions. The resulting reciprocity of the struts is highlighted in panels, as shown in Figures 4(d) and 4(i). The struts overlaid on the membrane are visualized in panels, as shown in Figures 4(e) and 4(j). The strut may pull the membrane in tension in the direction of its axis, and the proximity of an area of the membrane to a strut end may determine the magnitude of pretension it undergoes. By maximizing the magnitude and equalizing the directions of the pretension the membrane undergoes, the structural performance of the system can be better assured.

[0029] Figure 5 is a schematic representation of a reciprocal pattern, according to another example embodiment. Reciprocal patterns that include valence polygons in the shape of a hexagon and a triangle are shown. To increase redundancy, valence polygons of shapes of higher edge count, such as hexagons, can be drawn, as well as patterns with multiple valence polygons.

[0030] The different patterns of struts combined with a textile membrane can result in various 3D spatial forms. The textile membrane, once fitted with the struts through some custom connection detail, may be able to assume a 3D form starting from a 2D state due to the interaction between the membrane surface and the struts. Transfer from potential energy in the system to kinetic energy is created due to the stretched elastic membrane wishing to shrink inwards to its original size, but the stiff struts prevent this from happening. This frustration of energy may be sufficient to drive the assembly into a 3D form.

[0031] Embodiments of the invention also provide a method of forming a structure. Figure 6 is a flowchart 600 illustrating a method of forming a structure, according to an example embodiment. At step 602, a membrane with tensile properties is provided. At step 604, a plurality of reciprocal patterning units are disposed within the membrane. Each reciprocal patterning unit comprises a plurality of struts and each of the plurality of struts are configured to provide tension forces in a plurality of opposing directions to an area of the membrane in each reciprocal patterning unit. Further, the membrane exerts compression forces on each of the plurality of struts, and each of the plurality of struts exert the tension forces on the membrane simultaneously to maintain structural integrity of the structure. The plurality of opposing directions may comprise four or more opposing directions. The method may further comprise configuring the plurality of struts as cross shapes or asterisk shapes. Optionally, at step 606, the structure is secured to ground at designated locations to induce final standing form. Selected struts disposed at the bottom of the structure may be secured in predesignated locations on the ground through a miscellaneous construction detail. Forcing these struts into position as such may cause the membrane to deform elastically, and maintaining the structure in the deformed state may confer residual stress that provides the structure's final form and stiffness.

[0032] In an implementation, the method further comprises configuring each reciprocal patterning unit to exhibit at least one degree of symmetry. The at least one degree of symmetry may comprise translational symmetry or rotational symmetry.

[0033] In another implementation, the area of the membrane in each reciprocal patterning unit comprises endpoints of the plurality of struts. In the implementation, the method further comprises configuring the endpoints of each of the plurality of struts to define an area corresponding to a polygon comprising three or more edges.

[0034] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A structure comprising:
 - a membrane with tensile properties; and
 - a plurality of reciprocal patterning units disposed within the membrane, wherein each reciprocal patterning unit comprises a plurality of struts and wherein each of the plurality of struts is configured to provide tension forces in a plurality of opposing directions to an area of the membrane in each reciprocal patterning unit,
 - wherein the plurality of opposing directions comprises four or more opposing directions, and
 - wherein the area of the membrane in each reciprocal patterning unit comprises endpoints of the plurality of struts, and
 - wherein the endpoints of each of the plurality of struts are configured to define an area corresponding to a polygon comprising three or more edges, and
 - wherein the membrane exerts compression forces on each of the plurality of struts, and
 - wherein each of the plurality of struts exerts the tension forces on the membrane simultaneously to maintain structural integrity of the structure.
2. The structure as claimed in any one of the preceding claims, wherein the plurality of struts are configured as cross shapes or asterisk shapes.
3. The structure as claimed in any one of the preceding claims, wherein each reciprocal patterning unit exhibits at least one degree of symmetry.
4. The structure as claimed in claim 3, wherein the at least one degree of symmetry comprises translational symmetry or rotational symmetry.
5. A method of forming a structure, comprising the steps of:
 - providing a membrane with tensile properties; and
 - disposing a plurality of reciprocal patterning units within the membrane, wherein each reciprocal patterning unit comprises a plurality of struts and wherein each of the plurality of struts is configured to provide tension forces in a plurality of opposing directions to an area of the membrane in each reciprocal patterning unit, and wherein the plurality of opposing directions comprise four or more opposing directions, and wherein the area of the membrane in each reciprocal patterning unit comprises endpoints of the plurality of struts; and

configuring the endpoints of each of the plurality of struts to define an area corresponding to a polygon comprising three or more edges,

wherein the membrane exerts compression forces on each of the plurality of struts, and

wherein each of the plurality of struts exerts the tension forces on the membrane simultaneously to maintain structural integrity of the structure.

6. The method as claimed in claim 5, further comprising configuring the plurality of struts as cross shapes or asterisk shapes.

7. The method as claimed in claim 5 or 6, further comprising configuring each reciprocal patterning unit to exhibit at least one degree of symmetry.

8. The method as claimed in claim 7, wherein the at least one degree of symmetry comprises translational symmetry or rotational symmetry.