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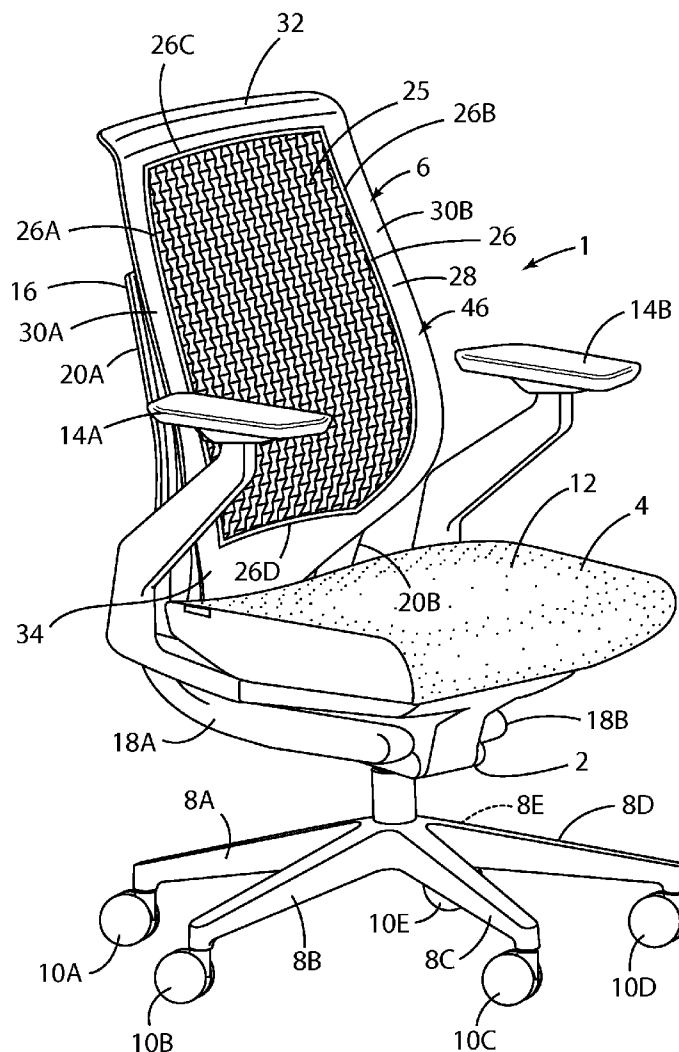
(19) **United States**(12) **Patent Application Publication**
Eberlein et al.(10) **Pub. No.: US 2015/0320220 A1**(43) **Pub. Date: Nov. 12, 2015**(54) **SEATING UNIT WITH AUXETIC USER
SUPPORT****Publication Classification**(71) Applicant: **Steelcase Inc.**, Grand Rapids, MI (US)(72) Inventors: **David C. Eberlein**, Hudsonville, MI (US); **Mark McKenna**, East Grand Rapids, MI (US); **Nickolaus William Charles Deevers**, Holland, MI (US); **Bruce M. Smith**, Grand Rapids, MI (US); **Fredric Biddle**, Kalamazoo, MI (US); **Brett Pearson**, Rockton, IL (US)(51) **Int. Cl.****A47C 5/12** (2006.01)**A47C 3/00** (2006.01)(52) **U.S. Cl.**CPC **A47C 5/12** (2013.01); **A47C 3/00** (2013.01)(21) Appl. No.: **14/699,648**(22) Filed: **Apr. 29, 2015****Related U.S. Application Data**

(60) Provisional application No. 61/989,396, filed on May 6, 2014.

(57)

ABSTRACT

A seating unit includes a generally horizontal seat portion and a generally upright back portion. The back portion includes a flexible membrane or mesh extending in first and second directions. The mesh defines a generally upright user support surface. At least a portion of the mesh comprises an auxetic material having a negative Poisson's ratio whereby stretching of the auxetic portion of the mesh in at least one of the first and second directions causes the mesh to expand in the other of the first and second directions.



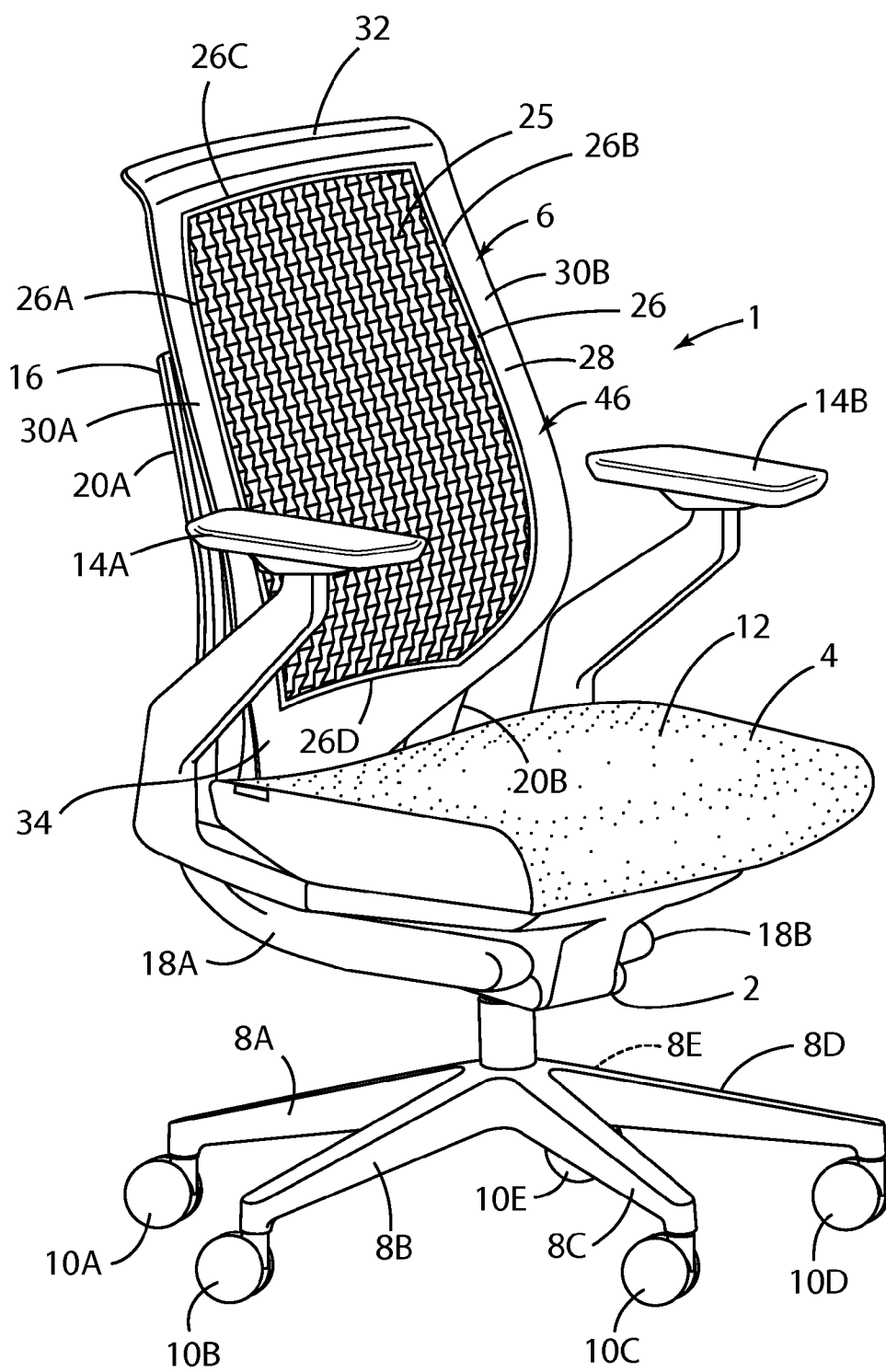


FIG. 1

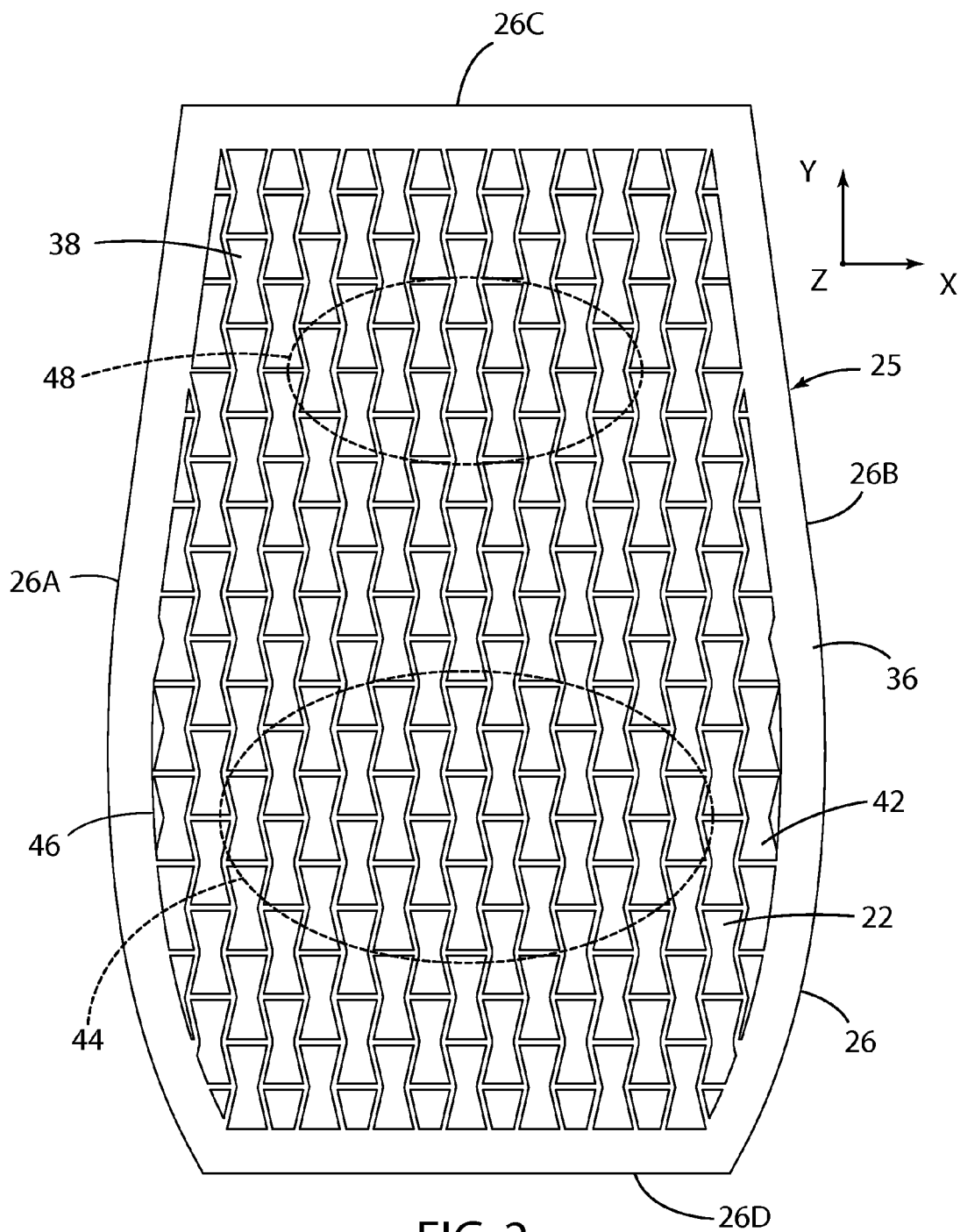
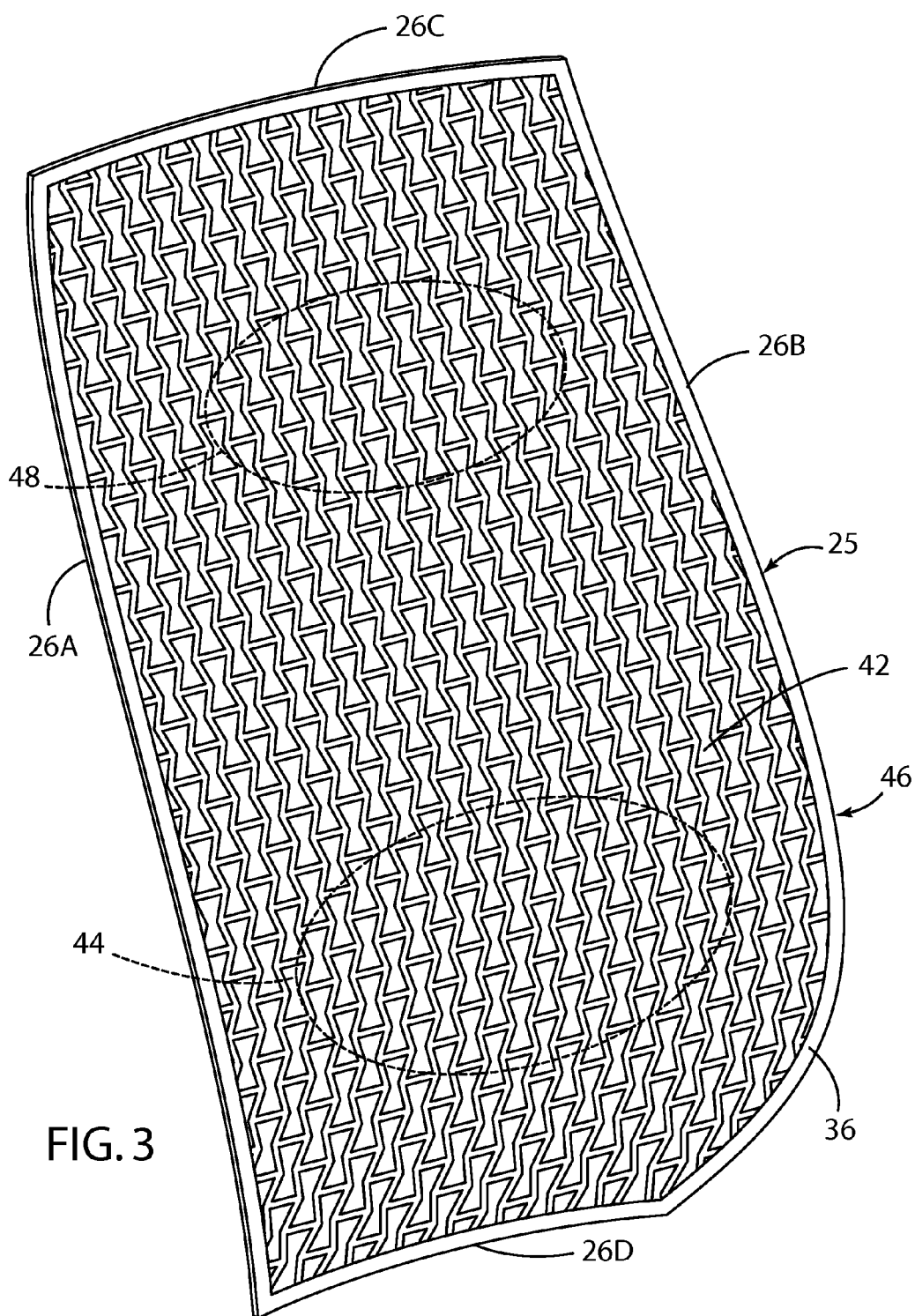


FIG. 2



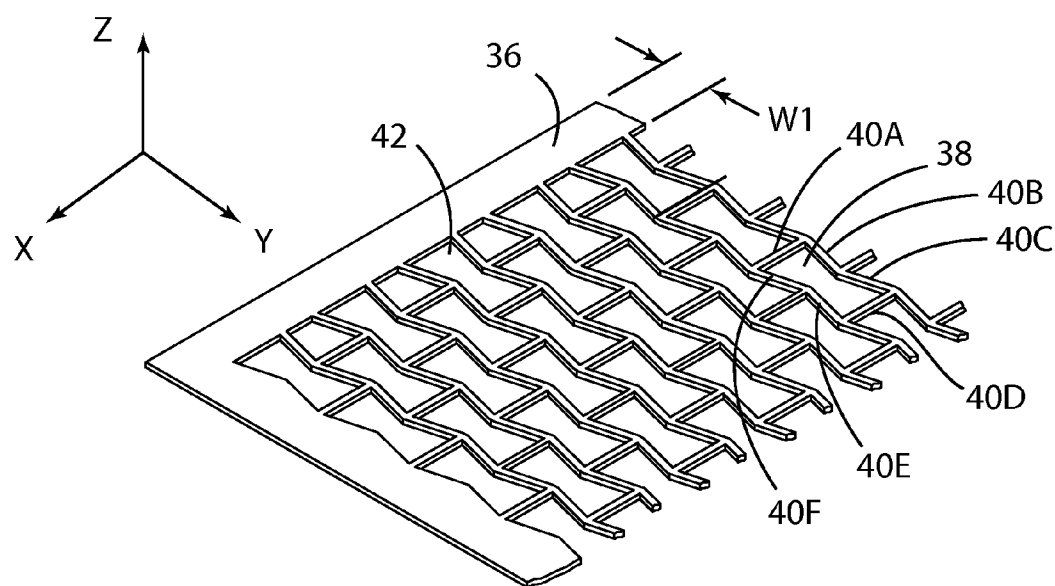


FIG. 4

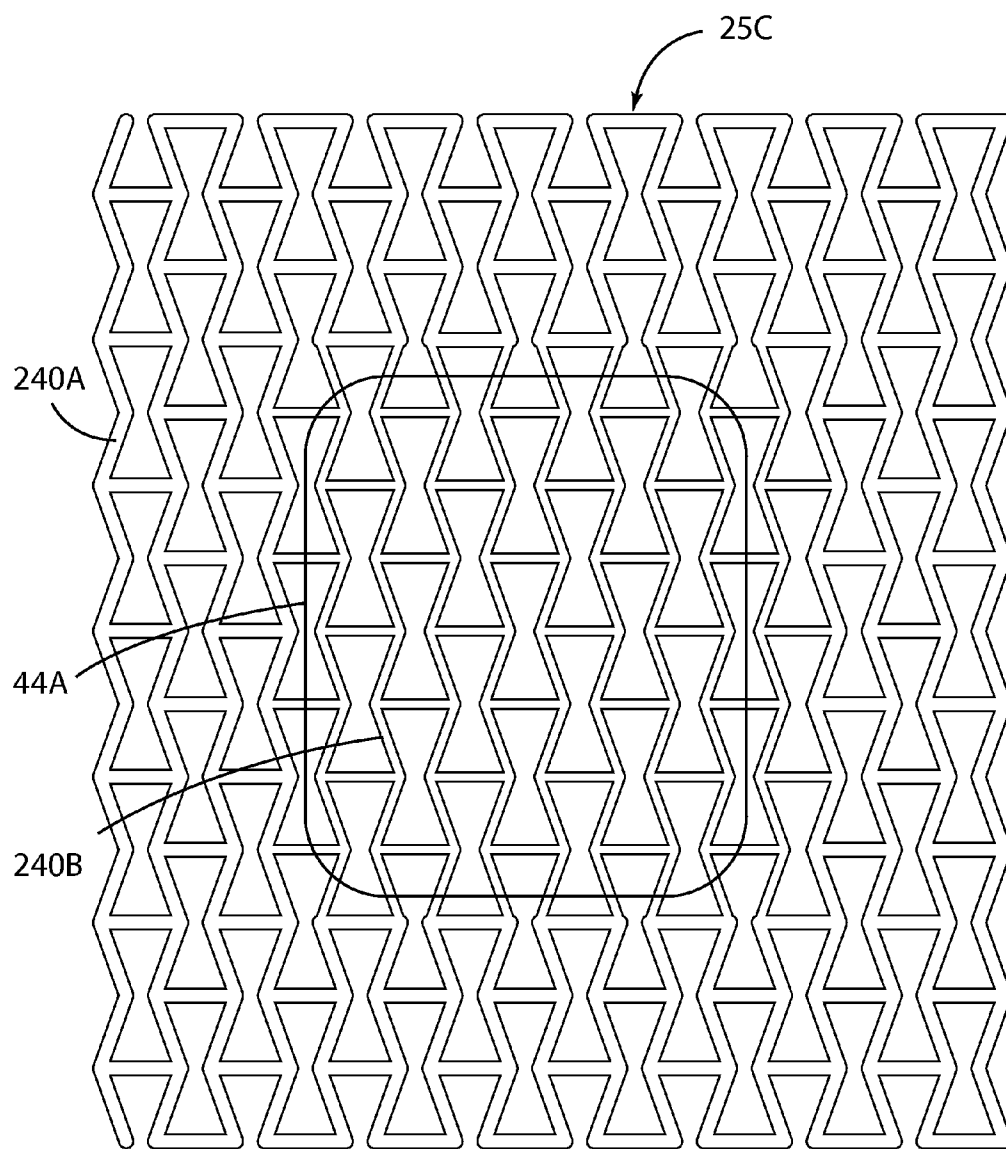
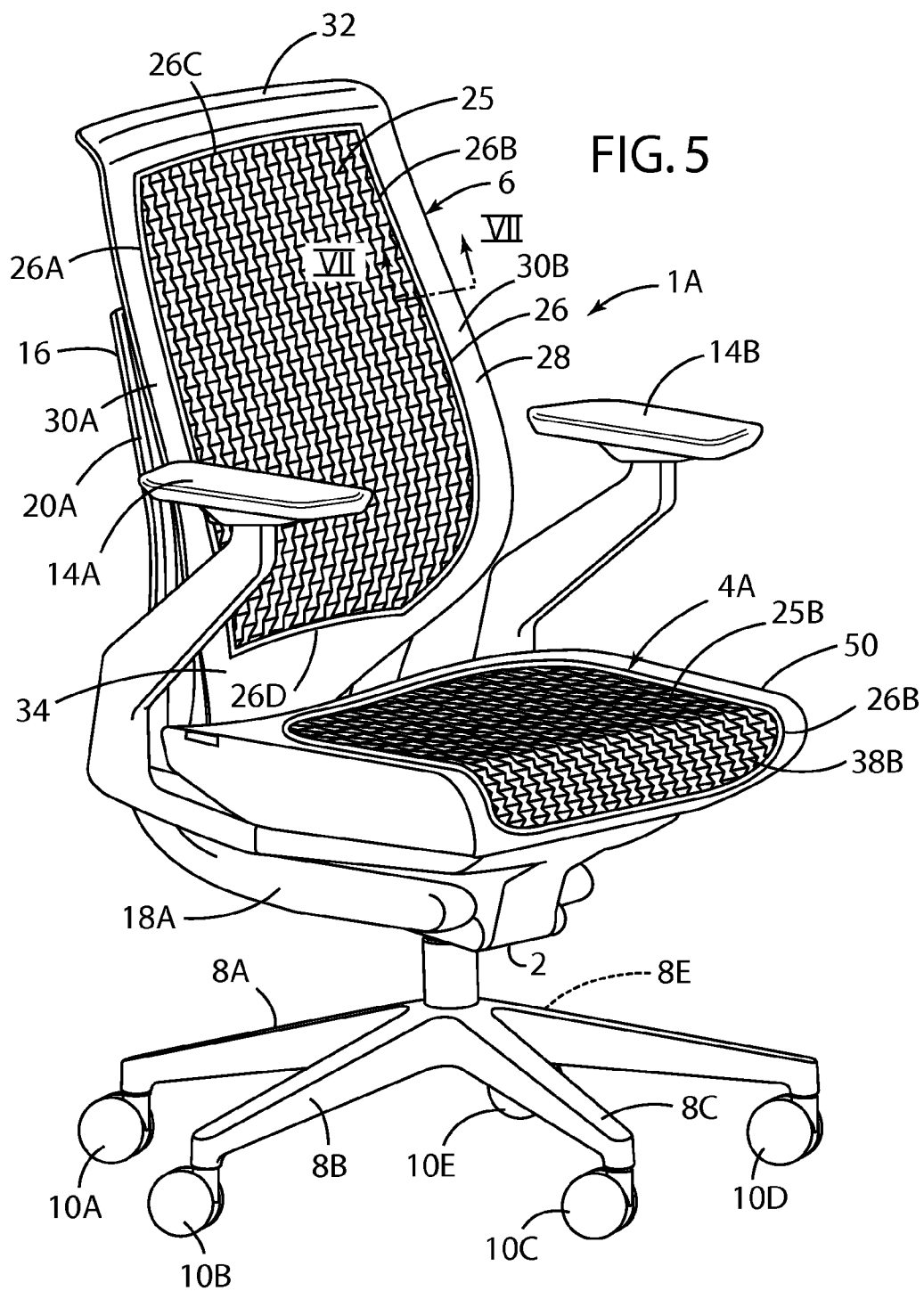


FIG. 4A



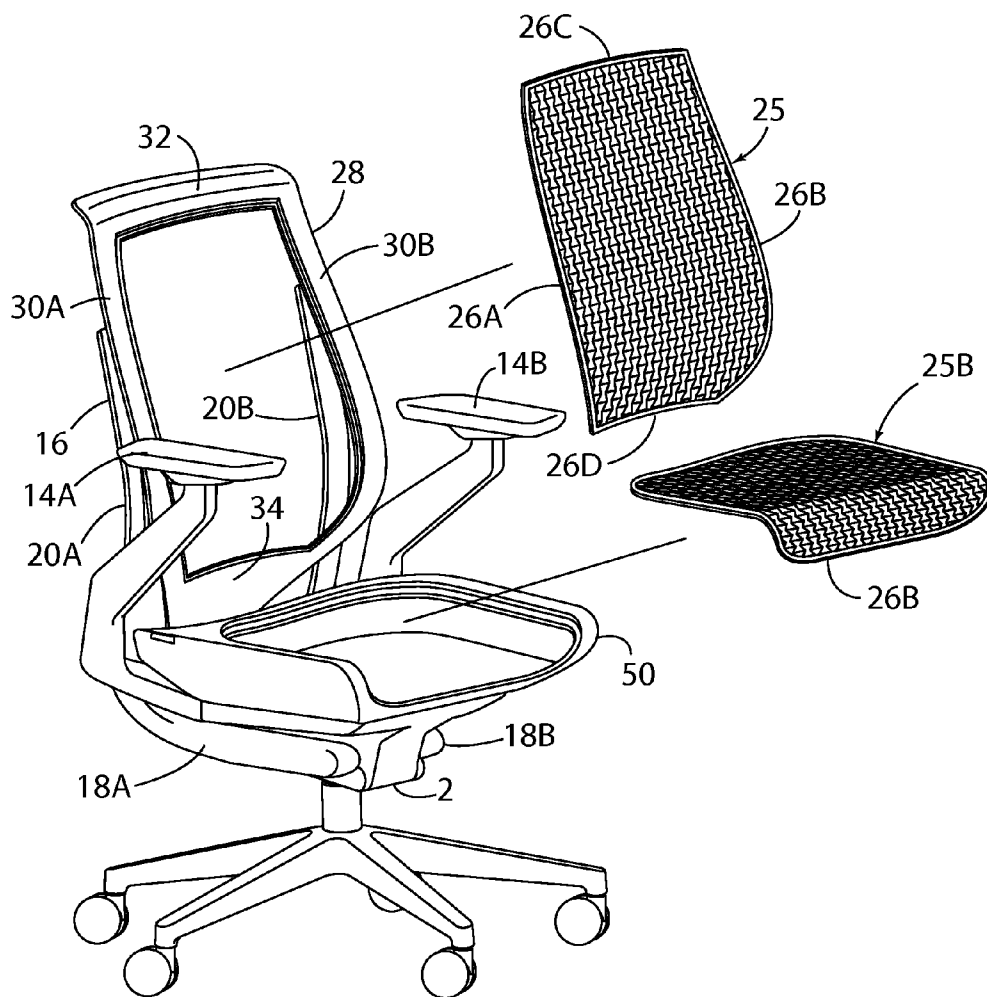
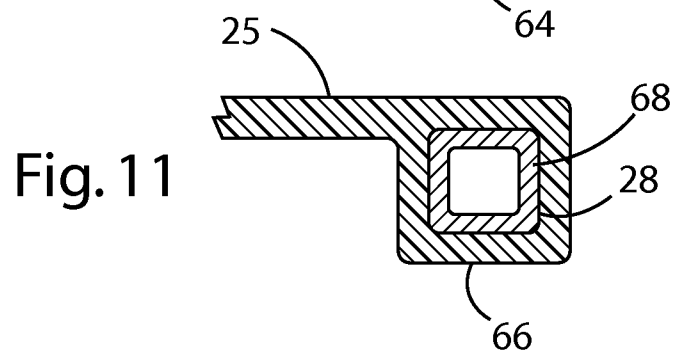
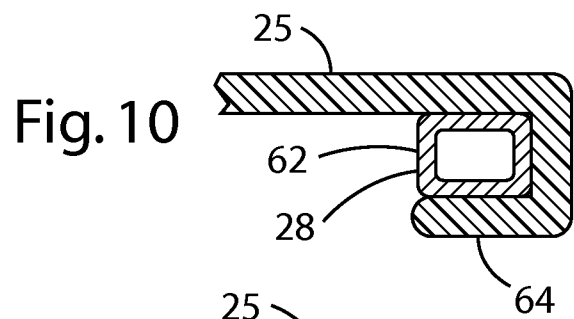
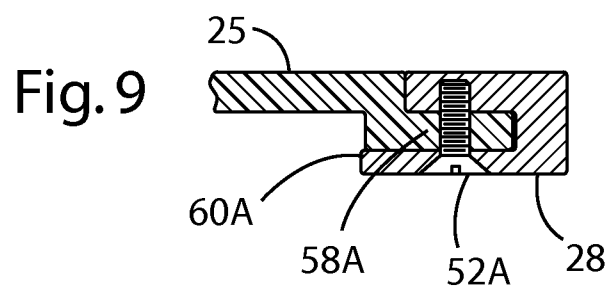
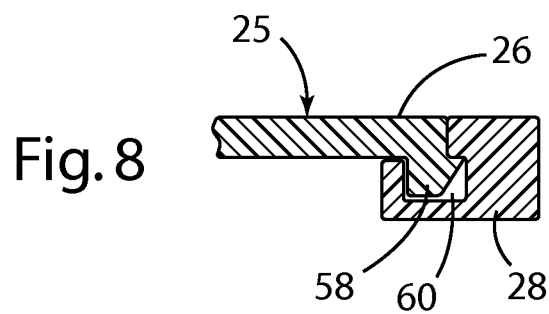
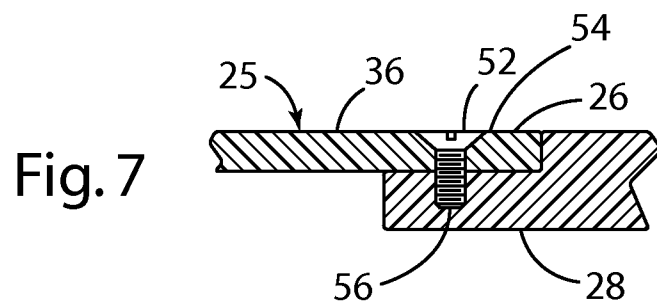


Fig. 6



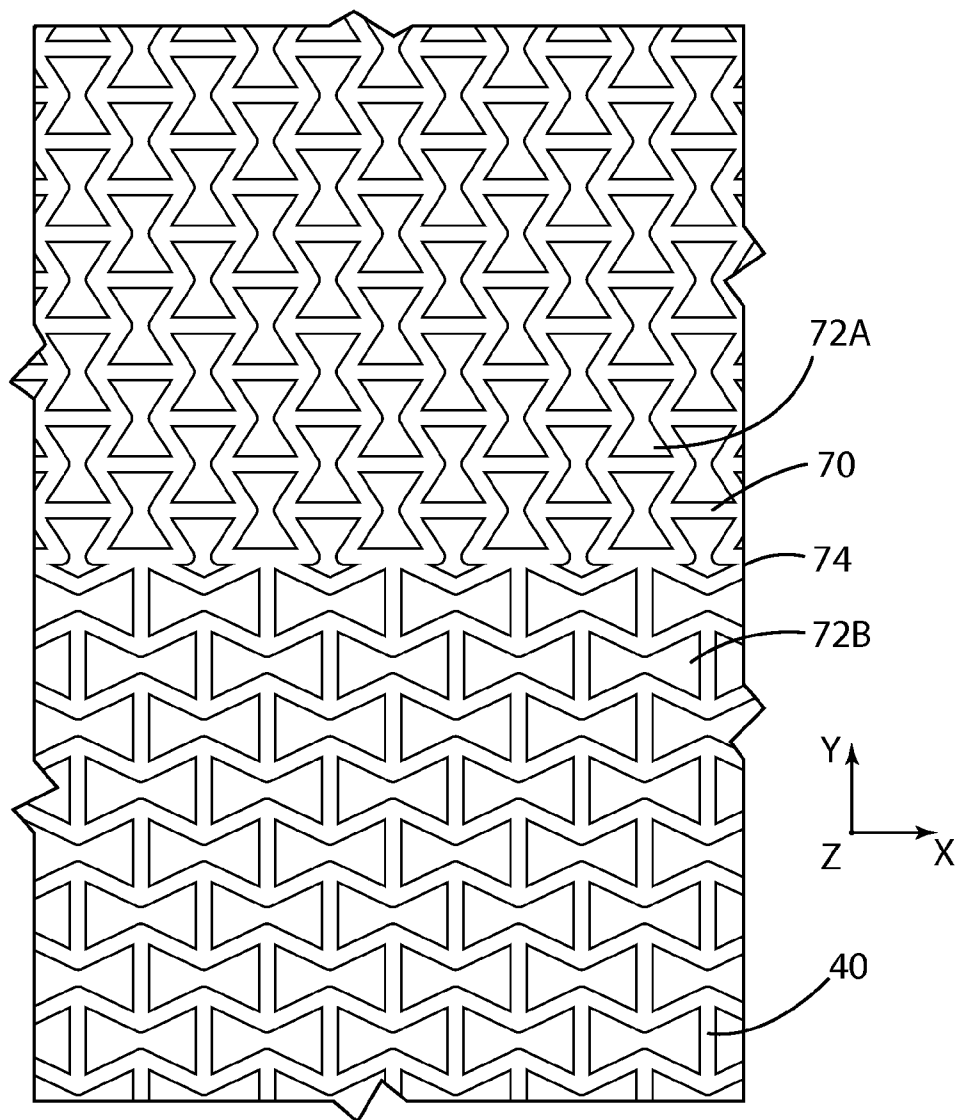


FIG. 12

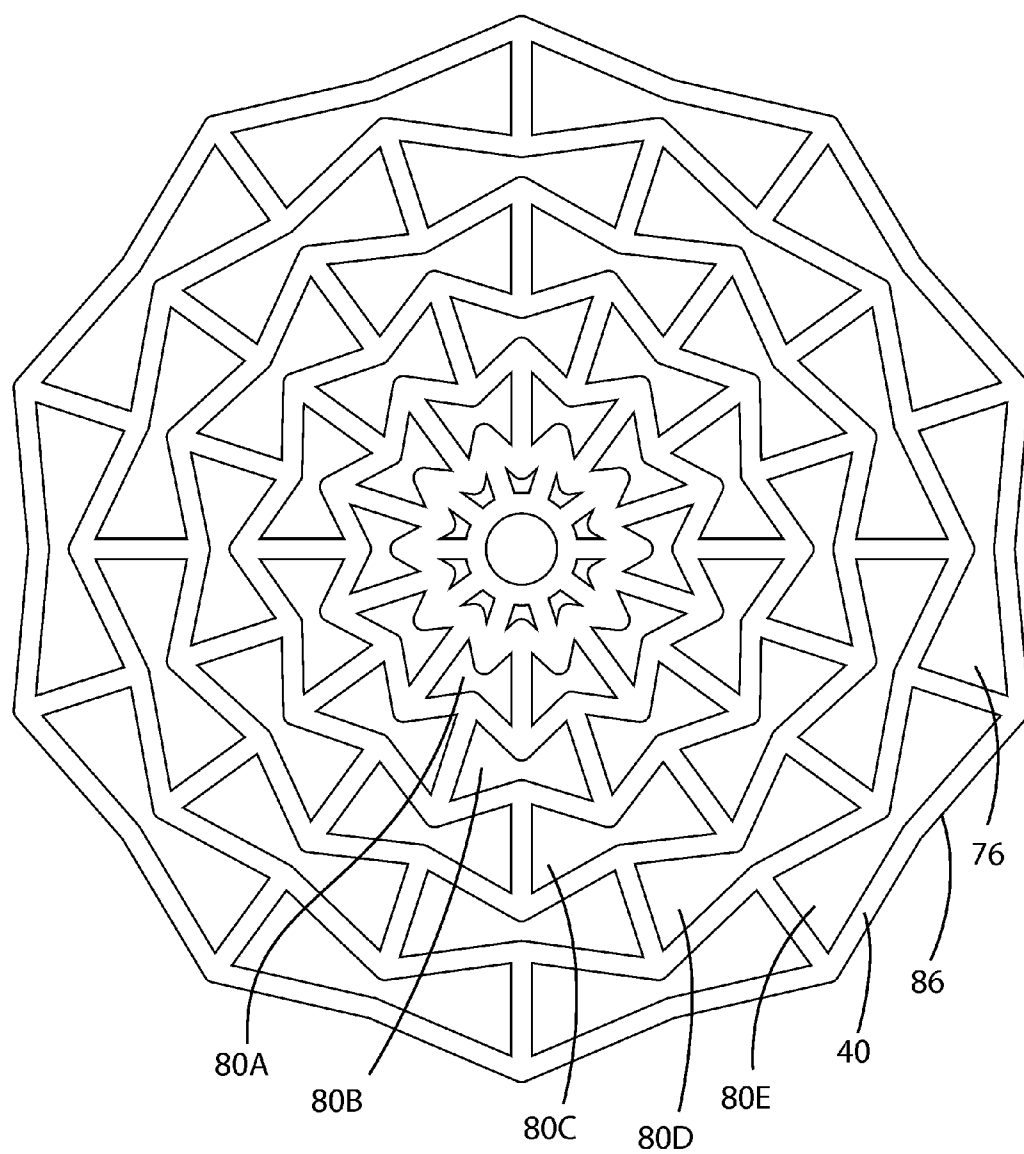
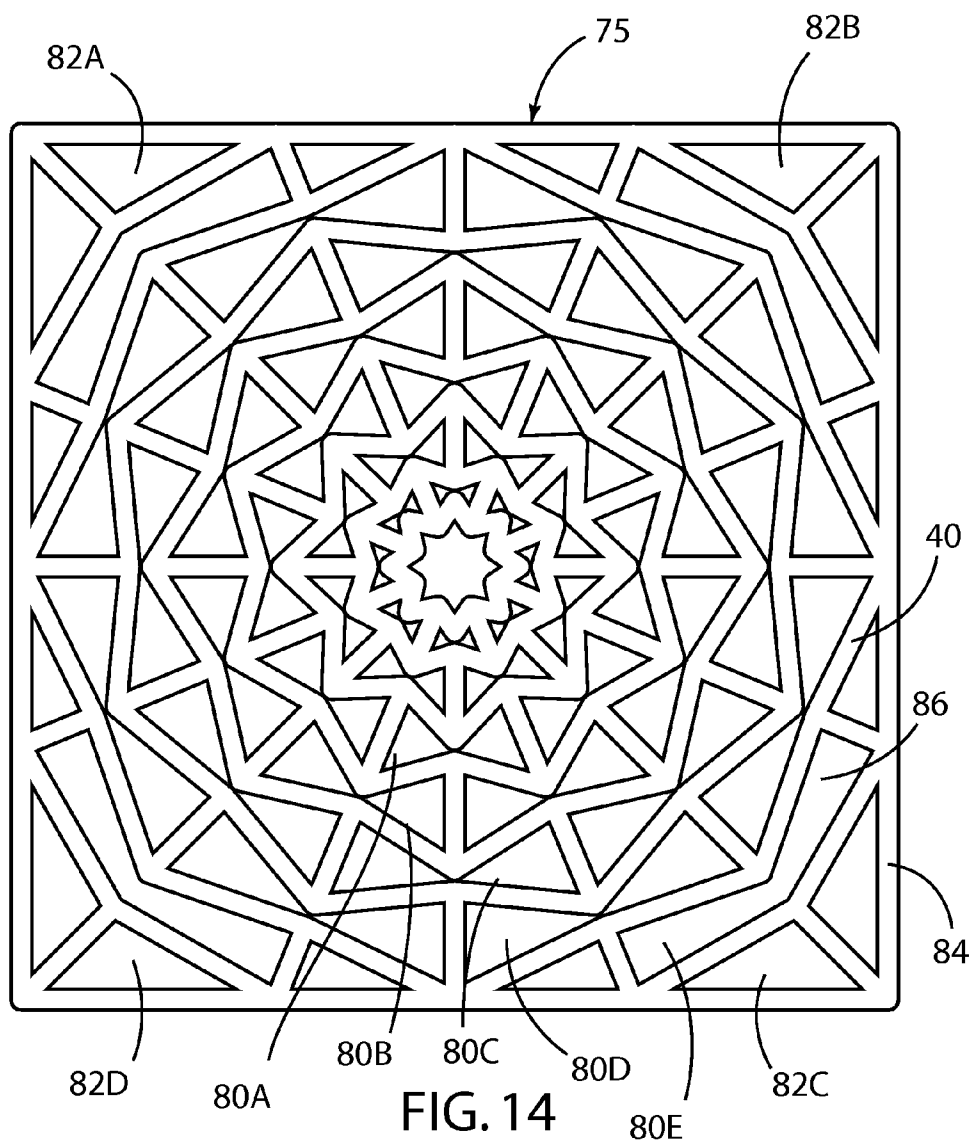


FIG. 13



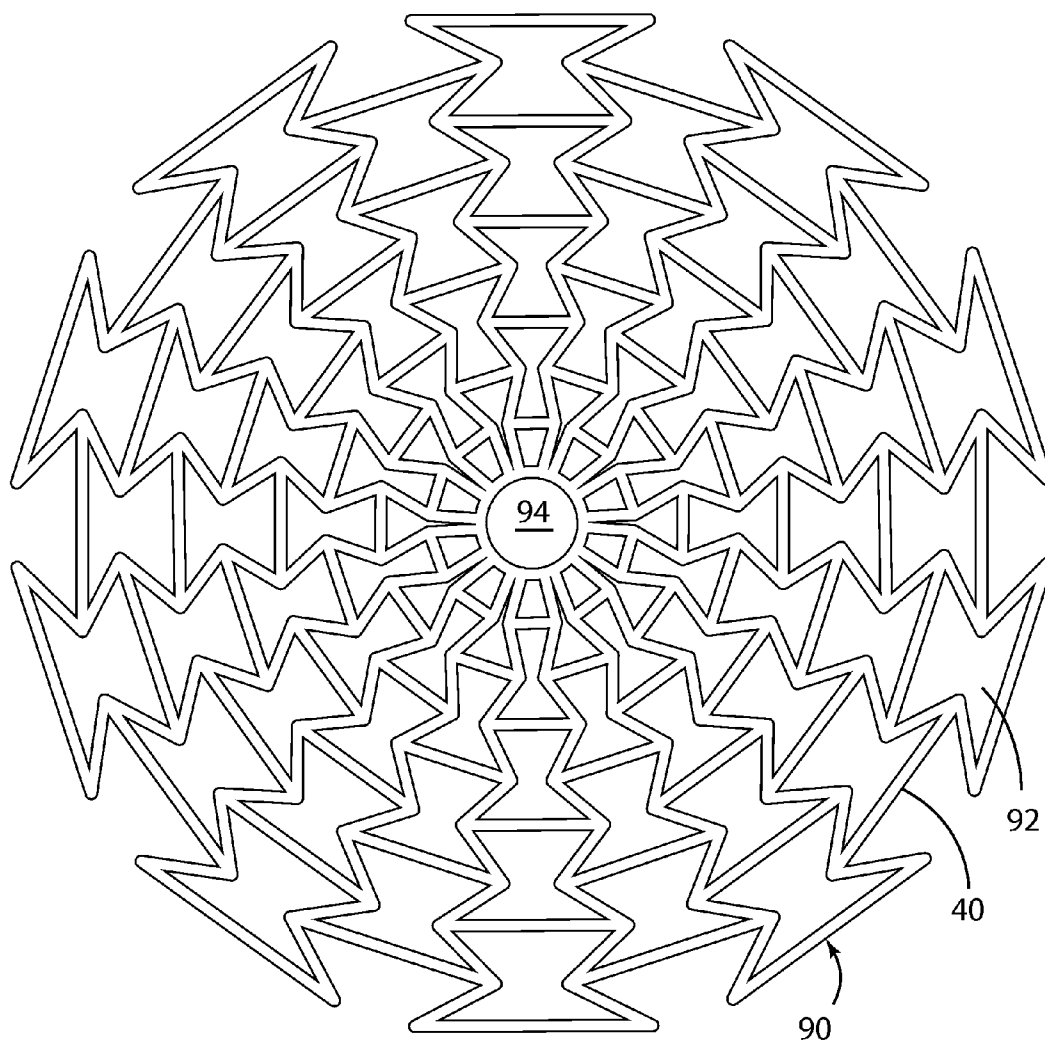


FIG. 15

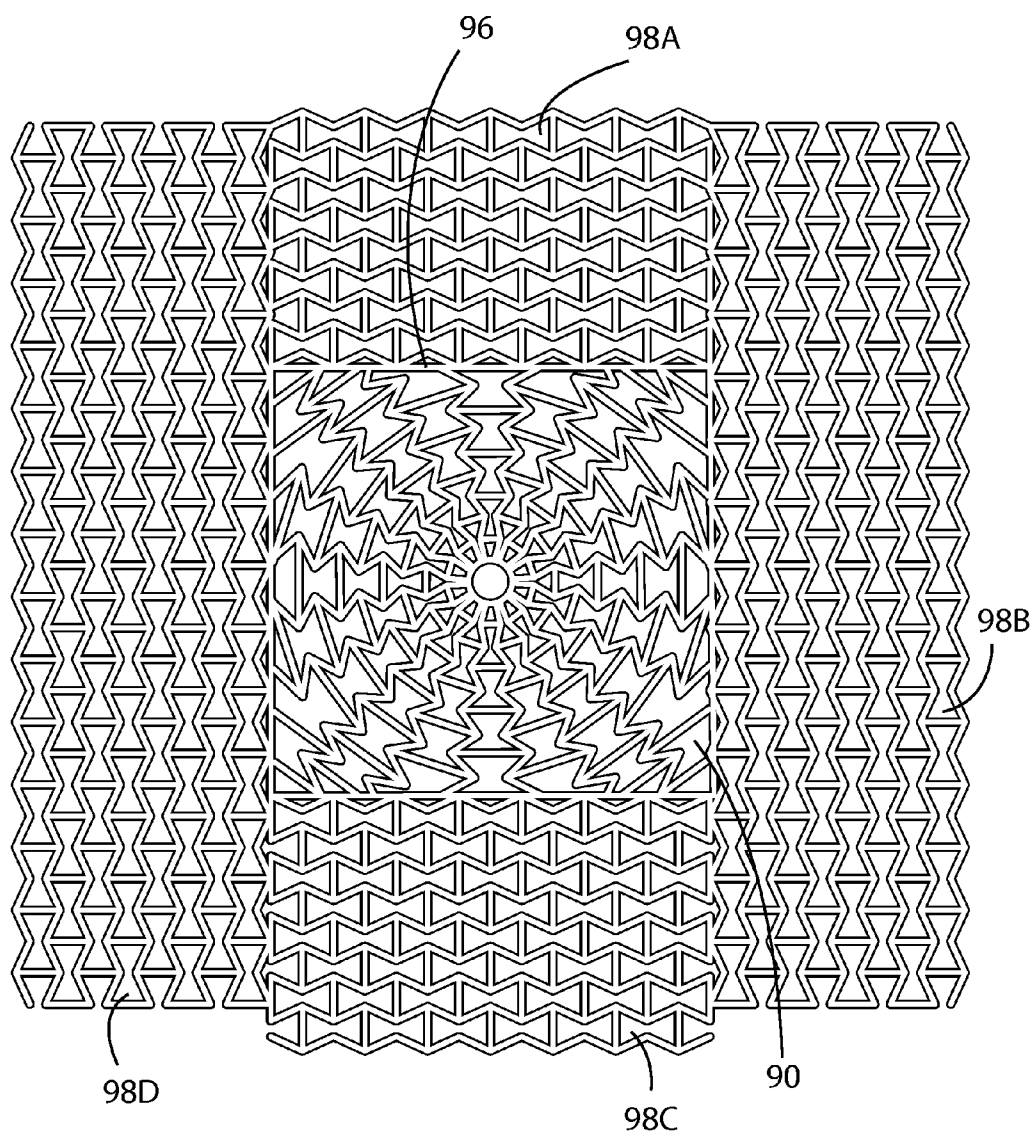


FIG. 16

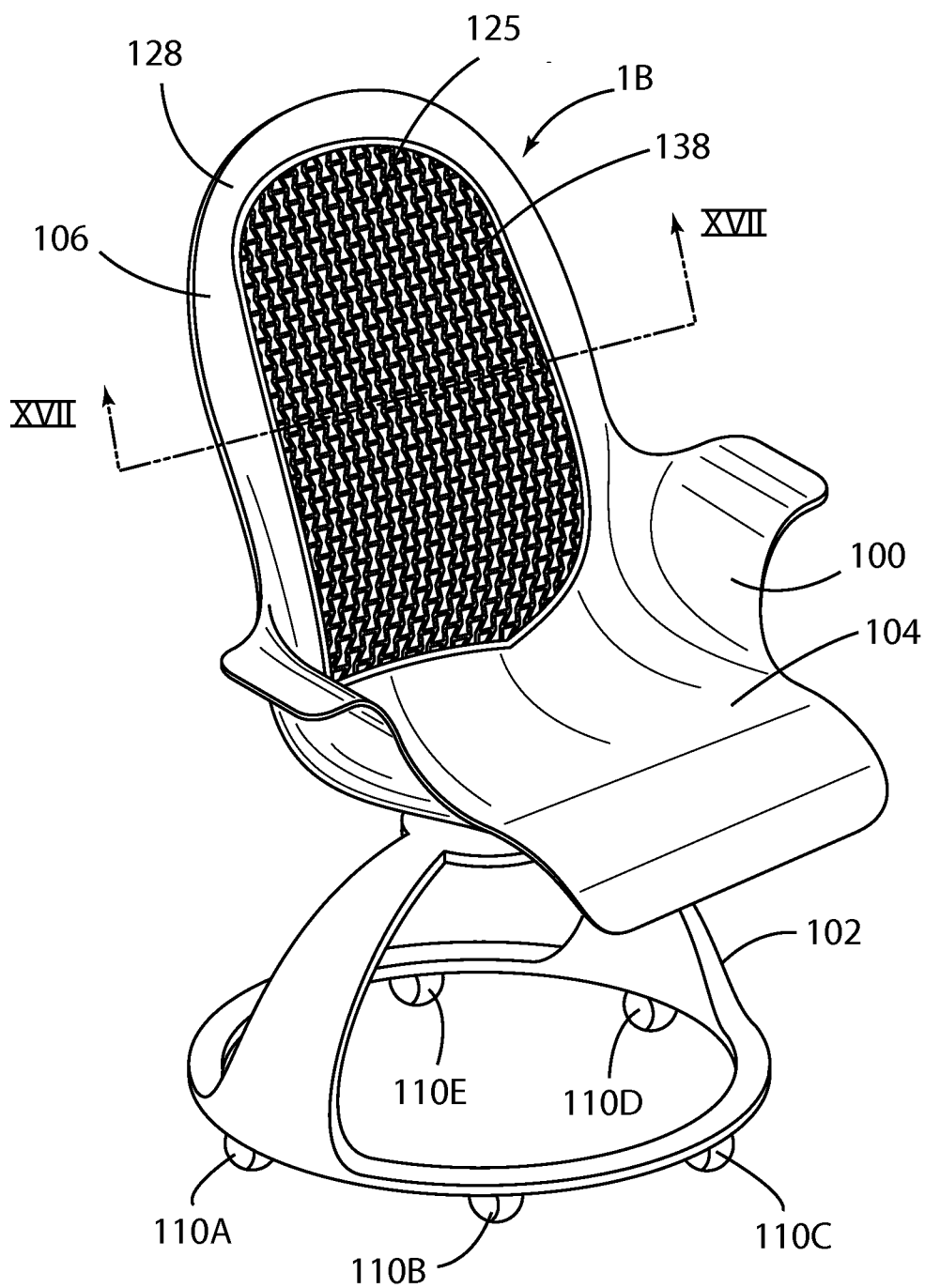


FIG. 17

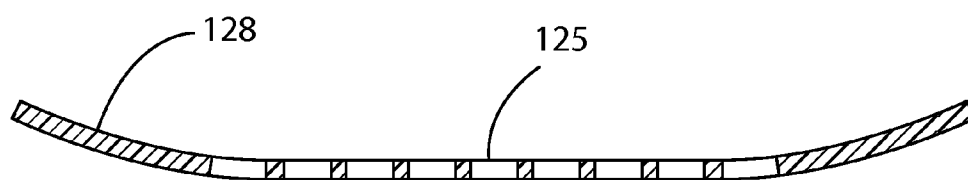


FIG. 18

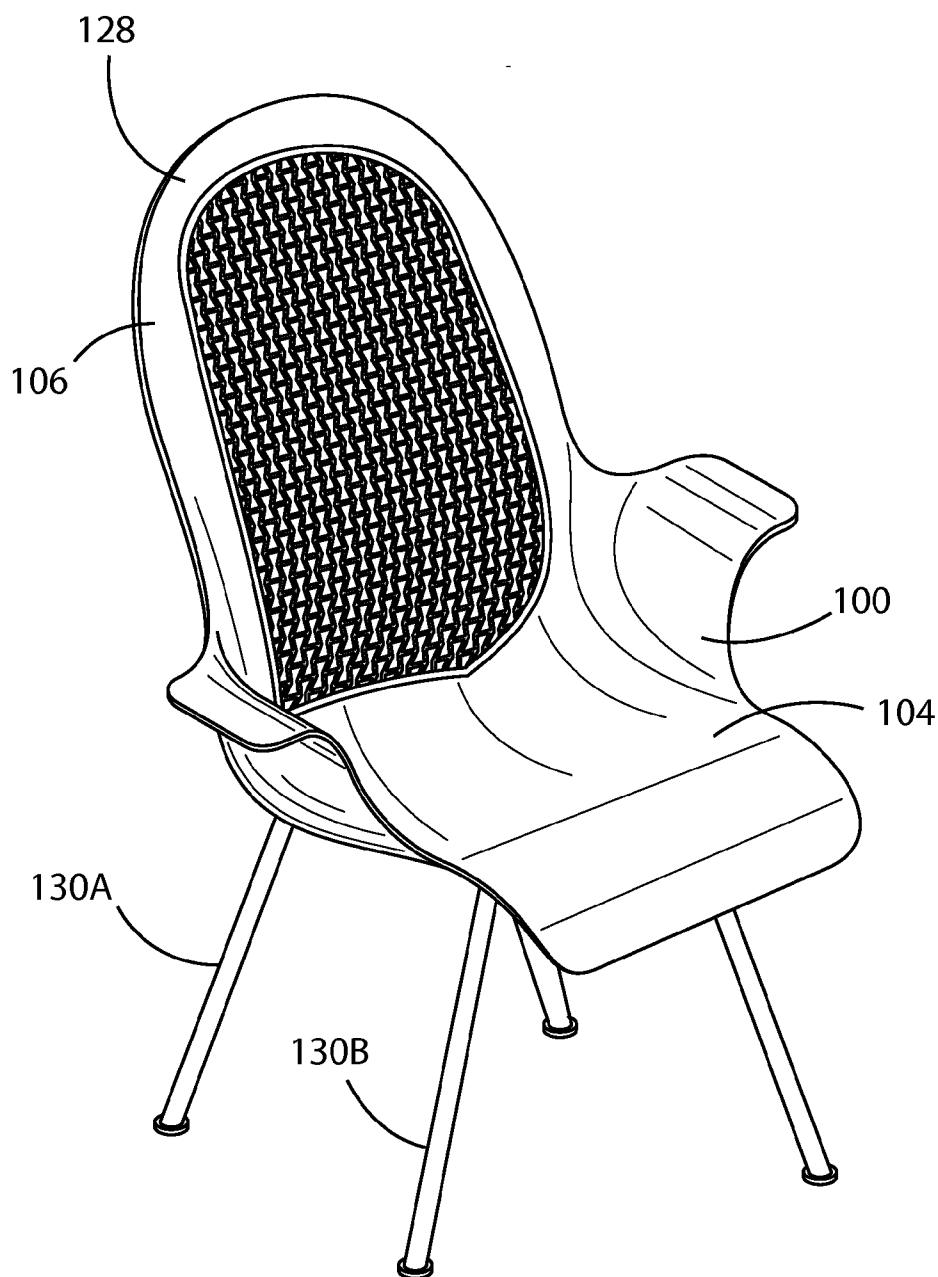


FIG. 19

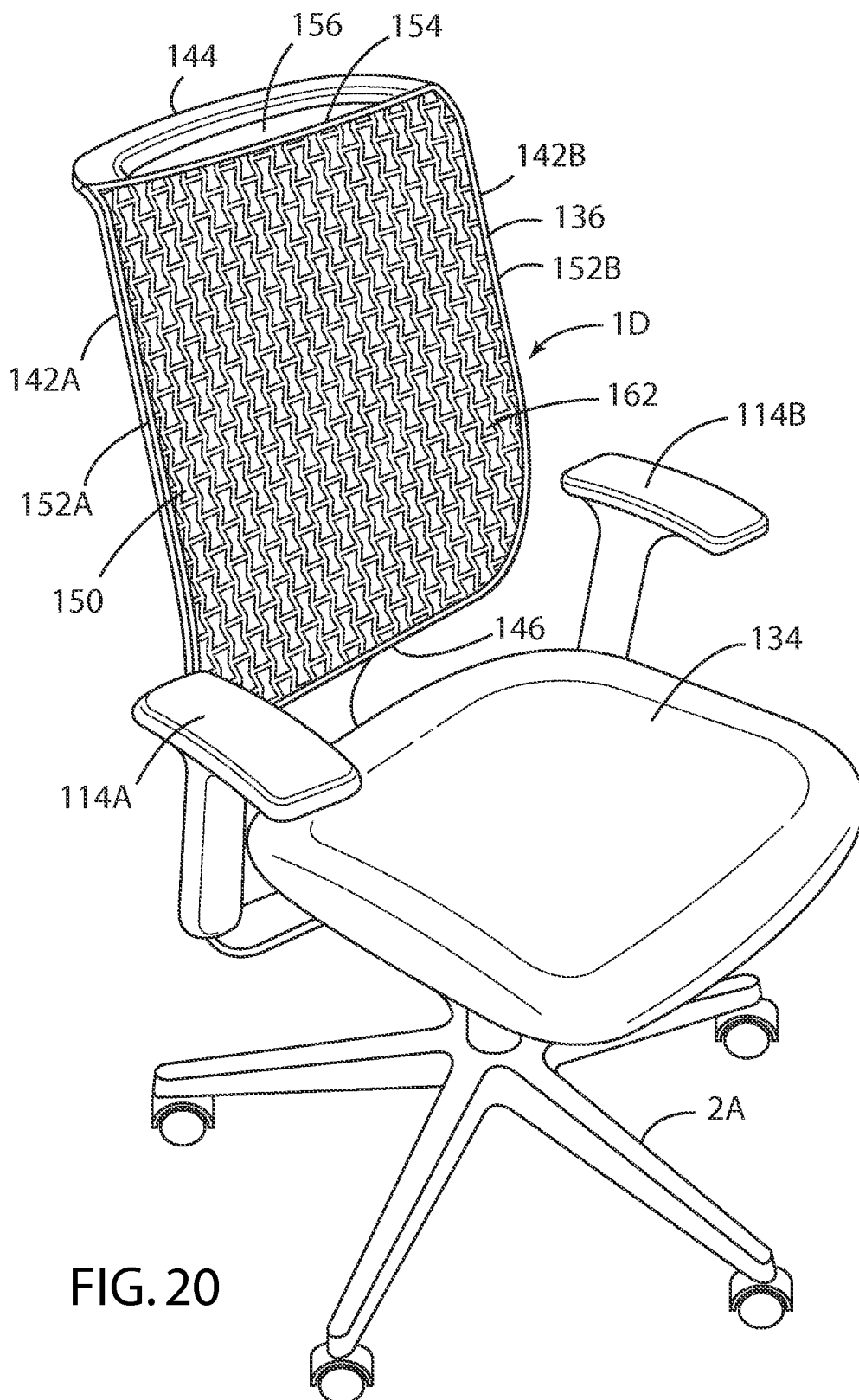
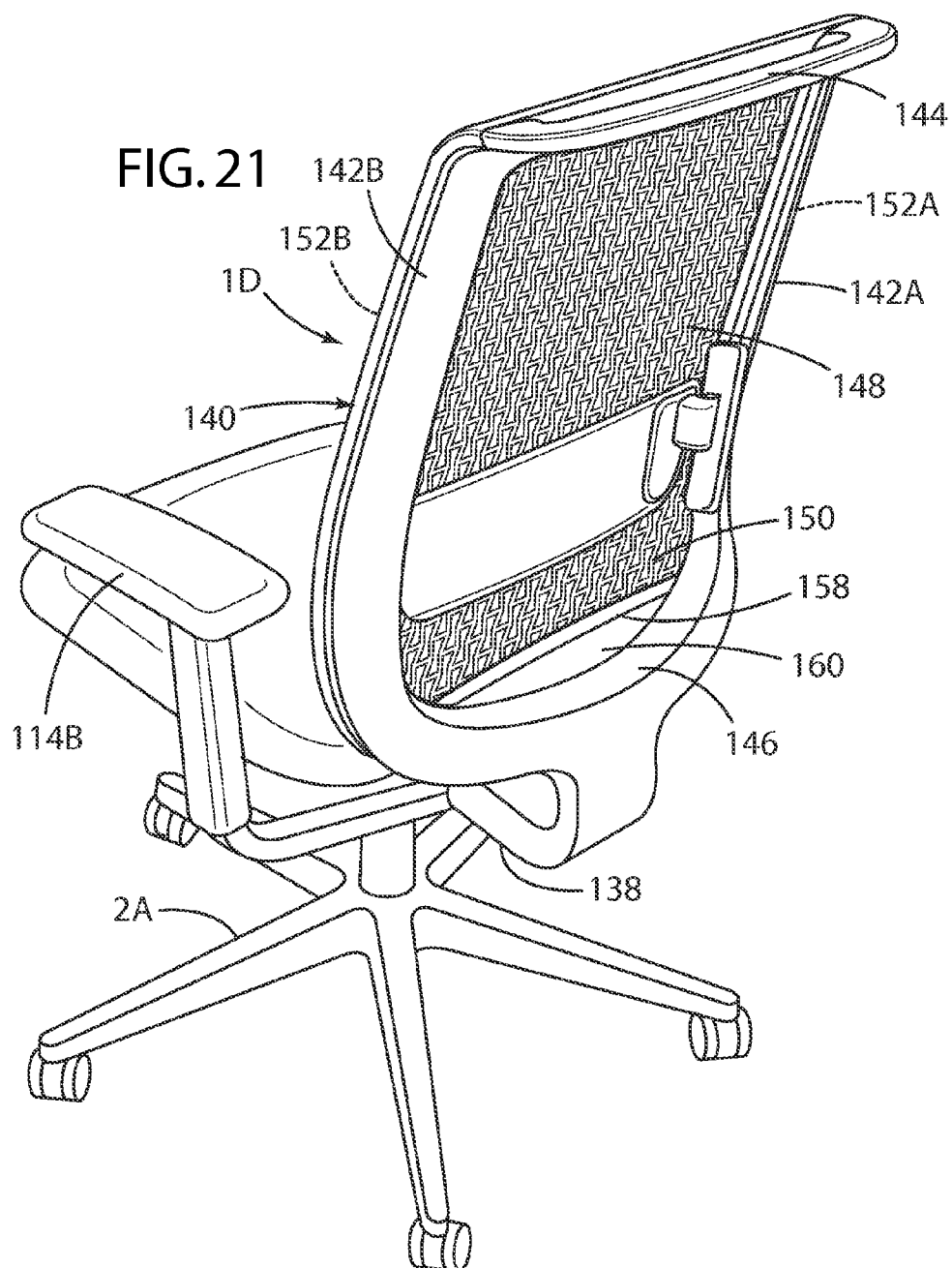


FIG. 20



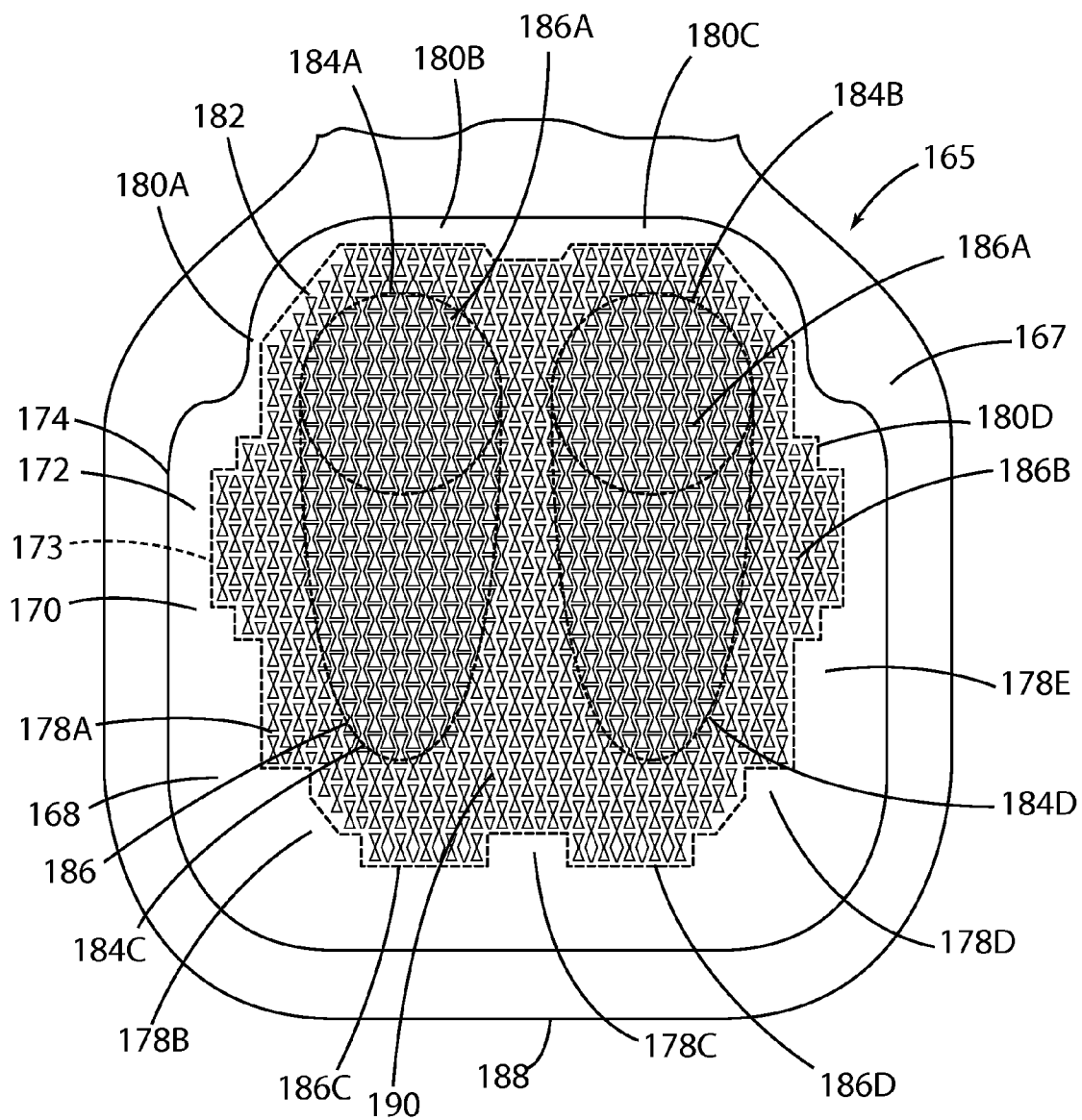


FIG. 22

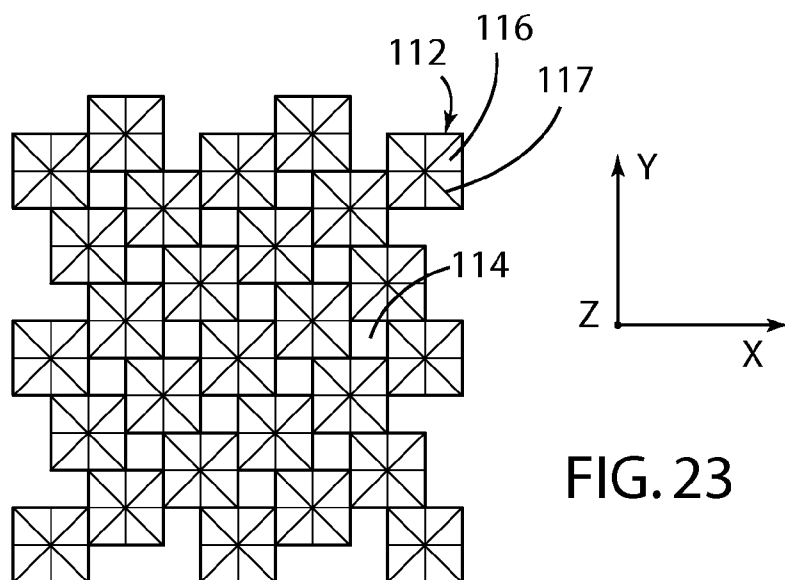


FIG. 23

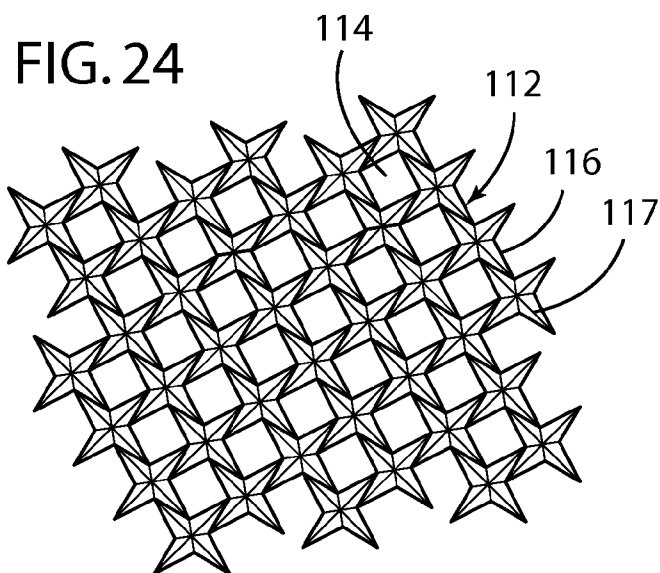


FIG. 24

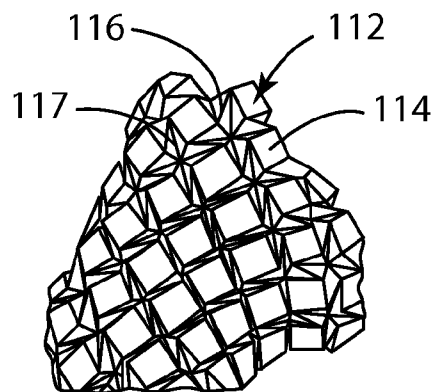
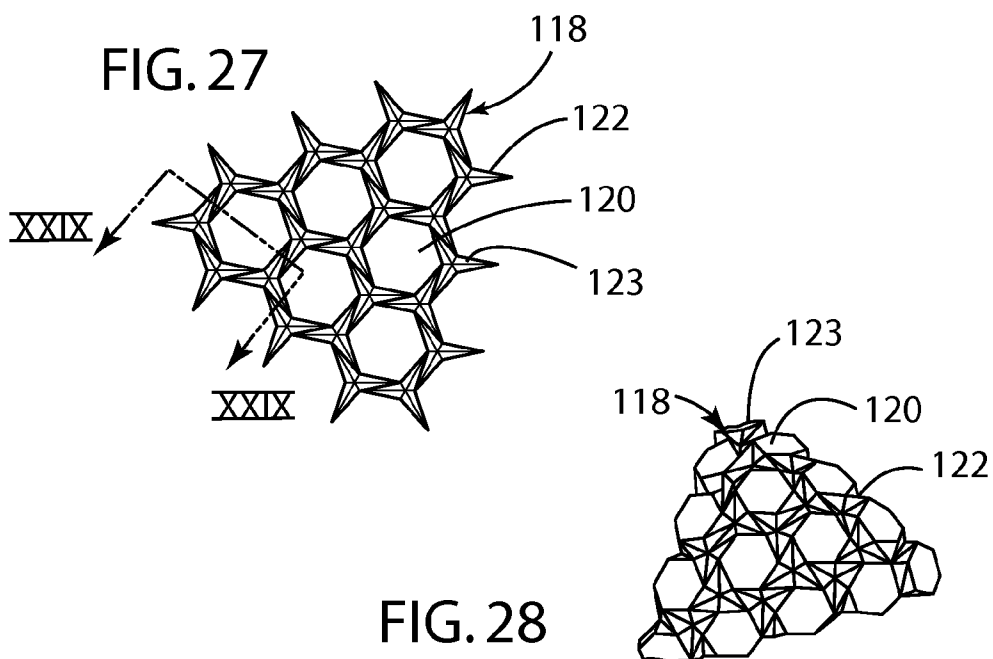
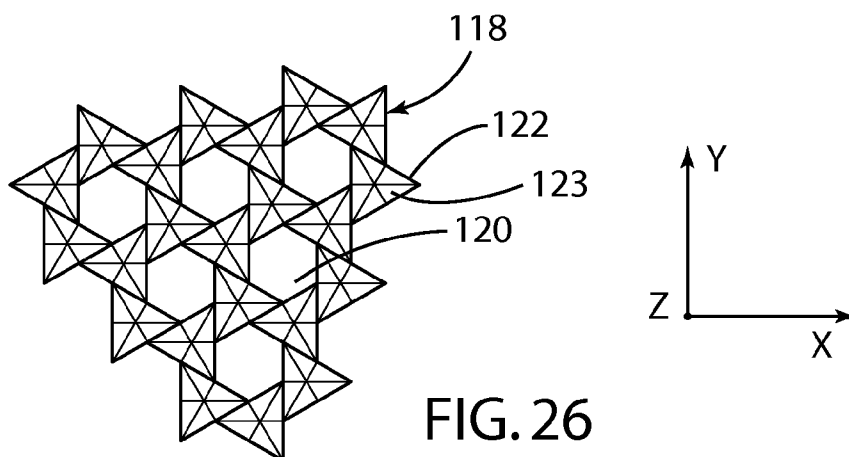


FIG. 25



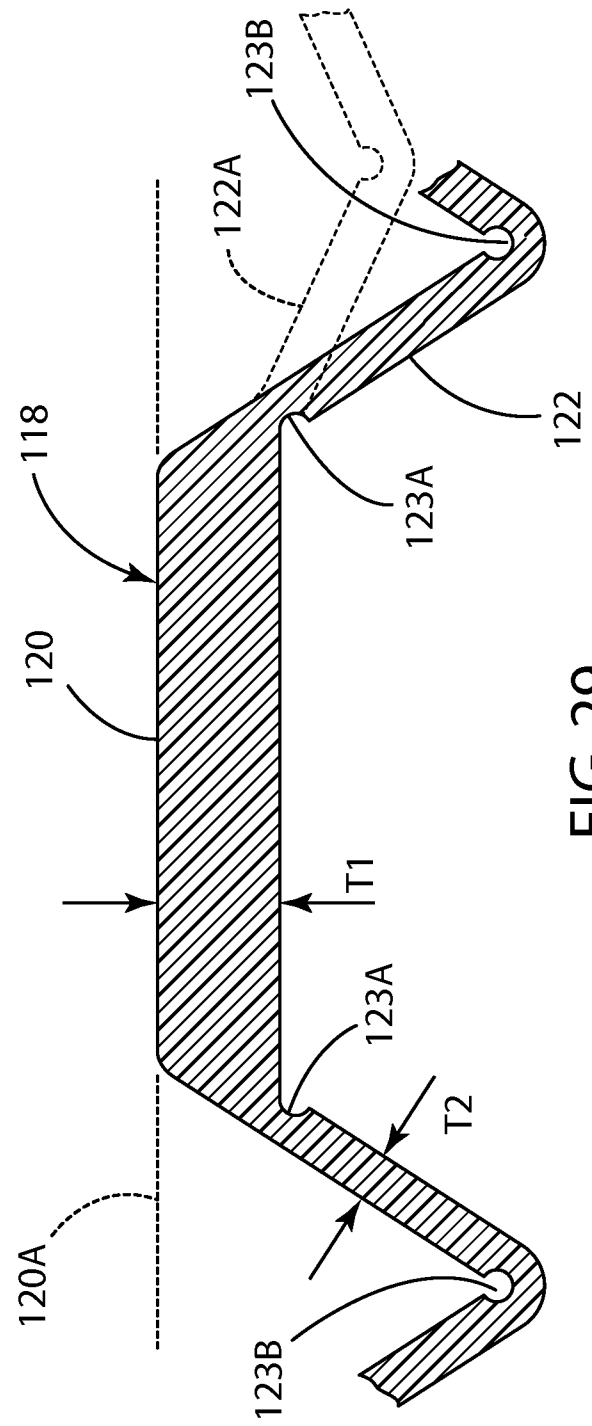


FIG. 29

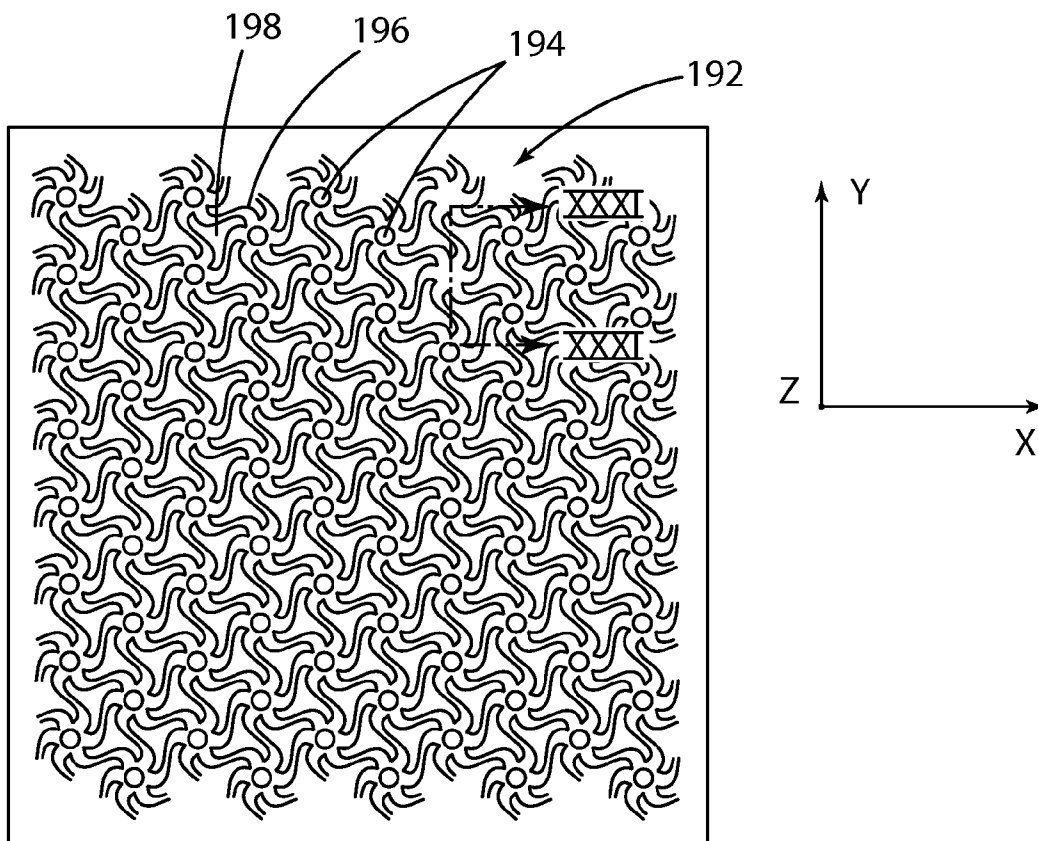


FIG. 30

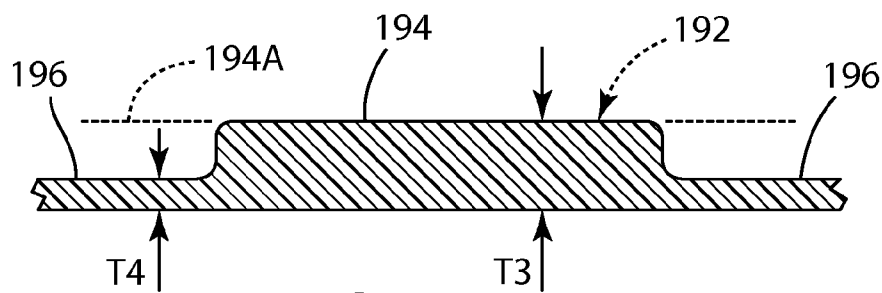


FIG. 31

SEATING UNIT WITH AUXETIC USER SUPPORT

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/989,396 filed on May 6, 2014, entitled, "SEATING UNIT WITH AUXETIC USER SUPPORT," the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] Various types of chairs, seating units, and other articles having user support surfaces have been developed. User supports may include foam or other resilient material that is provided in an effort to improve the comfort of a user. However, known user supports may suffer from various drawbacks.

SUMMARY OF THE INVENTION

[0003] One aspect of the present invention is a seating unit including a lower portion that is configured to support the seating unit. The seating unit may comprise a chair, and the lower portion may be configured to support the chair on a floor surface. The seating unit also may include a seating structure supported by the lower portion. The seating structure includes a generally horizontal seat portion and a generally upright back portion. The back portion may include upright frame portions defining a space therebetween and a flexible mesh extending in first and second directions across the space. The flexible mesh may be connected to the upright frame portions to define a generally upright user support surface. At least a portion of the flexible mesh comprises an auxetic material having a negative Poisson's ratio whereby stretching of the auxetic portion of the flexible mesh in at least one of the first and second directions tends to cause the flexible mesh to expand in the other of the first and second directions. The flexible mesh may comprise a molded polymer material such as polypropylene.

[0004] Another aspect of the present invention is a user support structure for seating units such as chairs. The user support structure includes a flexible membrane defining front and rear faces and opposite edge portions. The flexible membrane includes a high pressure region that is configured to support portions of a user's body when a user's body comes into contact with the high pressure region of the flexible membrane. The flexible membrane defines a lower pressure region adjacent the high pressure region. The high pressure region and the lower pressure region comprise auxetic material whereby stretching of the flexible membrane in a first direction tends to cause the material to expand in a second direction that is transverse to the first direction. The flexible membrane is significantly more compliant in the high pressure region than the lower pressure region in response to a force that is applied to the front face of the flexible membrane. The user support structure further includes a pair of spaced apart frame portions extending along the opposite edge portions of the flexible membrane. The opposite edge portions of the membrane are connected to the frame portions. The opposite edge portions of the membrane may be integrally formed with the frame portions.

[0005] Another aspect of the present invention is a user support for seating units or other articles having a surface

configured to support a user. The user support comprises a polymer mesh material including a plurality of links forming interconnected auxetic cells. Each auxetic cell has a length defined along a first cell axis and a width defined along a second cell axis that is transverse to the first cell axis. The auxetic cells comprise a plurality of interconnected flexible links configured such that stretching of the auxetic cells along the length of the auxetic cells causes the width of the auxetic cells to increase. A plurality of the auxetic cells are arranged about a center in a generally circular pattern to provide a region having increased compliance. The auxetic cells may be arranged such that the first cell axes are arranged in a radial pattern about the center, or in a circumferential pattern about the center.

[0006] These and other features, advantages, and objects of the present invention will be further understood and appreciated by those skilled in the art by reference to the following specification, claims, and appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is an isometric view of a chair according to one aspect of the present invention;

[0008] FIG. 2 is a view of a user support surface of the chair of FIG. 1;

[0009] FIG. 3 is an isometric view of a user support surface of the chair of FIG. 1;

[0010] FIG. 4 is a partially fragmentary isometric view of auxetic material of the chair of FIG. 1;

[0011] FIG. 4A shows an auxetic membrane or mesh according to another aspect of the present invention;

[0012] FIG. 5 is an isometric view of a chair according to another aspect of the present invention including a back support having auxetic material and a seat portion having auxetic material;

[0013] FIG. 6 is an exploded isometric view of the chair of FIG. 5;

[0014] FIG. 7 is a cross sectional view of a portion of the chair of FIG. 5 taken along the line VII-VII;

[0015] FIG. 8 is a cross sectional view of a portion of a chair according to another aspect of the present invention;

[0016] FIG. 9 is a cross sectional view of a portion of a chair according to another aspect of the present invention;

[0017] FIG. 10 is a cross sectional view of a portion of a chair according to another aspect of the present invention;

[0018] FIG. 11 is a cross sectional view of a portion of a chair according to another aspect of the present invention;

[0019] FIG. 12 is a partially fragmentary view of an auxetic material according to another aspect of the present invention;

[0020] FIG. 13 shows an auxetic material according to another aspect of the present invention;

[0021] FIG. 14 shows an auxetic material according to another aspect of the present invention;

[0022] FIG. 15 shows an auxetic material according to another aspect of the present invention;

[0023] FIG. 16 shows an auxetic material according to another aspect of the present invention;

[0024] FIG. 17 is an isometric view of a chair according to another aspect of the present invention;

[0025] FIG. 18 is a cross sectional view of the chair of FIG. 17 taken along the line XVII-XVII;

[0026] FIG. 19 is an isometric view of a chair according to another aspect of the present invention;

[0027] FIG. 20 is an isometric view of a chair according to another aspect of the present invention;

[0028] FIG. 21 is an isometric view of the chair of FIG. 20;
 [0029] FIG. 22 is a partially fragmentary plan view of a user support surface according to another aspect of the present invention;

[0030] FIG. 23 shows an auxetic membrane according to another aspect of the present invention in an expanded state;

[0031] FIG. 24 shows the auxetic membrane of FIG. 23 in a contracted state;

[0032] FIG. 25 is an isometric view of the auxetic membrane of FIGS. 23 and 24;

[0033] FIG. 26 shows an auxetic membrane according to another aspect of the present invention in an expanded state;

[0034] FIG. 27 shows the auxetic membrane of FIG. 23 in a contracted state;

[0035] FIG. 28 is an isometric view of the auxetic membrane of FIGS. 23 and 24;

[0036] FIG. 29 is a cross sectional view of the auxetic membrane of FIG. 27 taken along the line XXIX-XXIX;

[0037] FIG. 30 is an auxetic membrane according to another aspect of the present invention; and

[0038] FIG. 31 is a cross sectional view of the auxetic membrane of FIG. 30 taken along the line XXXI-XXXI.

DETAILED DESCRIPTION

[0039] For purposes of description herein, the terms “upper,” “lower,” “right,” “left,” “rear,” “front,” “vertical,” “horizontal,” and derivatives thereof shall relate to the invention as oriented in FIG. 1. However, it is to be understood that the invention may assume various alternative orientations, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification are simply exemplary embodiments of the inventive concepts defined in the appended claims. Hence, specific dimensions and other physical characteristics relating to the embodiments disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

[0040] With reference to FIG. 1, a seating unit such as a chair 1 according to one aspect of the present invention includes a lower portion such as base 2, a seat portion 4, and a back portion 6. The base 2 may include a plurality of structural members 8A-8E and rollers 10A-10E that are configured to support the chair 1 on a floor surface. However, chair 1 may include other base structures as discussed in more detail below in connection with FIGS. 17 and 19. Furthermore, the present invention could comprise a seat unit for stadiums, vehicles, aircraft, ships, or virtually any other application.

[0041] The seat portion 4 includes an upwardly-facing support surface 12 that may comprise fabric or other material that extends over a foam core (not shown). Chair 1 may optionally include armrests 14A and 14B. The armrests 14A and 14B may have virtually any configuration as required for a particular application.

[0042] The back portion 6 of chair 1 includes a support structure 16 having lower portions 18A and 18B that movably interconnect the back portion 6 to the base 2. The support structure 16 may also include upwardly-extending supports 20A and 20B (see also FIG. 6) that are joined with lower portions 18A and 18B. The lower portions 18A and 18B may be joined with the upper portions 20A and 20B, respectively, such that support structure 16 has an L-shape in plan view. However, it will be understood that the back portion 6 and the

base 2 may have virtually any configuration, and the present invention is not limited to the specific structures 18A, 18B, 20A, and 20B.

[0043] The back portion 6 may also include a membrane or mesh 25 having a perimeter 26 that is connected to a back frame structure 28. As discussed in more detail below, at least a portion of membrane or mesh 25 has a negative Poisson's ratio such that the membrane comprises an auxetic material. The perimeter 26 of auxetic membrane or mesh 25 may include side portions 26A and 26B that are connected to upright frame portions 30A and 30B, respectively, of back frame structure 28. The auxetic membrane or mesh 25 may also include an upper perimeter portion 26C that is connected to upper horizontal frame portion 32 of back frame structure 32. Auxetic membrane or mesh 25 may further include a lower perimeter portion 26D that is connected to a horizontal lower frame portion 34. As discussed in more detail below, the auxetic membrane or mesh 25 may comprise molded polypropylene or other suitable polymer material. Furthermore, the auxetic membrane or mesh 25 may be integrally formed (e.g. molded) with the back frame structure 28 to form a one-piece molded polypropylene structure. Alternatively, the mesh 25 and frame structure 28 may be integrally formed from other suitable materials. Also, as discussed in more detail below in connection with FIG. 6, the auxetic membrane or mesh 25 may comprise a separate component that is secured to the back frame structure 28.

[0044] With further reference to FIGS. 2-4, the perimeter portions 26A-26D of auxetic membrane 25 may comprise an integral edge band portion 36. The edge band 36 may comprise a ring-like structure extending around an auxetic central portion 22 of auxetic membrane or mesh 25. As shown in FIG. 4, the edge band 36 may have a width “W1” that is approximately constant around the perimeter 26 of auxetic membrane 25. The edge band 36 may also have a substantially uniform thickness around perimeter 26. The width W1 of edge band 36 may be about 0.25 inches to about 1.00 inches, and the thickness may be about 0.050 inches to about 0.25 inches. However, the width W1 may fall outside these ranges according to other aspects of the present invention.

[0045] With reference to FIG. 4, the central portion 22 of auxetic membrane or mesh 25 includes a plurality of auxetic cells 38 that are formed by individual links 40A-40F. In the illustrated example, the links 40A-40F form a “bowtie” shape. However, various types of auxetic patterns or materials may also be utilized according to other aspects of the present invention. Referring again to FIG. 2, in the illustrated example, auxetic cells 38 extend in a first direction “Y” and a second direction “X.” Due to the geometry of the links 40A-40D, if the membrane 25 is stretched in the direction Y, the individual auxetic cells 38 will tend to expand in the second direction X such that the mesh 25 has a negative Poisson's ratio. Thus, if an out of plane force in the Z-direction is applied to a front face 42 of auxetic membrane or mesh 25, the force will generate in-plane tension in the X-Y plane of the membrane 25. Expansion (stretching) of the auxetic cells 38 in the Y direction thereby causes expansion of the auxetic cells 38 in the X direction. The expansion of the auxetic cells 38 in the X and Y directions causes, or results from, movement/deformation/flexing of membrane 25 in an out of plane Z direction. It will be understood that the term auxetic, as used herein, may refer to auxetic materials comprising a single molecule, or a particular structure of macroscopic matter that is configured to provide a negative Poisson's ratio.

[0046] Referring again to FIG. 4, the auxetic cells 38 may all have substantially the same size and shape, and the auxetic cells 38 may be oriented in substantially the same manner. Furthermore, each of the links 40A-40F may have substantially the same cross-sectional shape and size. However, the cross-sectional shapes and thicknesses of the individual links 40A-40F may be varied to provide increased compliance in certain regions of the auxetic membrane 25. For example, with reference to FIG. 2, the auxetic membrane 25 may include a high pressure region 44 corresponding to a lumbar region 46 of back portion 6 (see also FIG. 1). In general, testing may be conducted to determine specific regions of the auxetic membrane 25 that are subject to higher loads when a user is seated in the seating unit 1, and these high pressure regions 44 can be mapped or otherwise identified. For example, a thin sheet of solid polymer material (not shown) may be installed in chair back 6 or seat 4A (FIG. 5) in place of auxetic membrane 25 for testing purposes, and the force/pressure distributions resulting from various test users can be recorded. The pressure/force data for numerous test users can be combined to define high pressure regions 44. In general, the high pressure regions correspond to portions of a user's body that generate higher forces per unit area (e.g. 1b/in²) on the test (e.g. solid) membrane.

[0047] The high pressure regions 44 of auxetic membrane or mesh 25 may be configured to provide additional flexibility or compliance to increase user comfort. Specifically, one or more of the links 40A-40F of the auxetic cells 38 within the high pressure region 44 may have reduced width or thickness to provide increased flexibility/compliance in the high pressure region 44. For example, the links 40A-40F outside of high pressure region 44 may have a square cross-sectional shape with a width of 0.100 inches and a thickness of 0.100 inches, whereas the links 40A-40F inside region 44 may have reduced (equal) width and thickness (e.g. 0.050 inches). An example of a membrane/mesh 25C having variable link thickness/width is shown in FIG. 4A. The links 240A outside of high pressure region 44A have increased width relative to the links 240B of high pressure region 44A. The links 240A and 240B may have square cross-sectional shapes (i.e. the links 240B have reduced thickness and width), or the links 240A and 240B may have the same thickness, with links 240B having reduced width. It will be understood that the dimensions will depend on the material used to form membrane or mesh 25 and the compliance required for a particular application. Alternatively, the links 40A-40F may have substantially the same width throughout mesh 25, but may have reduced thickness (e.g. 0.050 inches) within high pressure region 44. Furthermore, the sizes and/or geometries of the auxetic cells 38 may also be varied to provide increased compliance in high pressure region 44. Also, the auxetic membrane or mesh 25 may include auxetic cells 38 within high pressure region 44, and the auxetic membrane or mesh 25 may include "conventional" non-auxetic mesh material (e.g. a rectangular or square grid) in regions outside of the high pressure region 44.

[0048] In a preferred embodiment, the auxetic membrane or mesh 25 comprises a one-piece molded polymer member. For example, the auxetic membrane or mesh 25 may comprise molded polypropylene or other suitable material. The auxetic membrane or mesh 25 may be configured to provide increased compliance/flexibility as required for a particular chair configuration to thereby provide a cushioning affect that may be similar to conventional padded chair support struc-

tures. The use of a molded polymer membrane or mesh provides a support surface that has significantly reduced cost and complexity relative to conventional padded user support surfaces. Still further, as discussed above, the auxetic membrane or mesh 25 may provide increased compliance/flexibility in certain areas or regions as required to provide increased comfort for a seated user. The compliance of the auxetic membrane or mesh 25 may optionally be controlled in specific regions to provide flexibility/compliance that is similar to the compliance of conventional padded supports/cushions. Additional regions such as upper back region 48 (FIGS. 2 and 3) may also be configured to have increased compliance/flexibility. It will be understood that the surface contour/shape of the auxetic membrane or mesh 25 may affect the size/shape/location of the high pressure regions 44, and the auxetic membrane or mesh 25 may therefore include specific regions having increased compliance/flexibility as required for a particular contour/shape of the membrane 25.

[0049] With further reference to FIG. 5, a seating unit or chair 1A according to another aspect of the present invention includes a back portion 6 that is substantially identical to the back portion 6 described in more detail above in connection with FIGS. 1-4. Seating unit or chair 1A also includes a seat portion 4A having an auxetic membrane or mesh 25B. The auxetic membrane or mesh 25B may have a plurality of auxetic cells 38 that are substantially identical to the auxetic cells 38 of auxetic membrane or mesh 25 as described in more detail above. The auxetic membrane or mesh 25B includes a perimeter 26B that is secured to a seat frame 50. The auxetic membrane or mesh 25B may comprise a separate component that is secured to the seat frame 50 as shown in FIG. 6. Alternatively, the auxetic membrane or mesh 25B may be integrally molded with the seat frame 50. The auxetic membrane or mesh 25B may include one or more high pressure regions having increased compliance/flexibility due to decreases in thickness of the individual links 40A-40F (FIG. 4), variations in the sizes of the auxetic cells 38, and/or other variations as required to provide the desired compliance.

[0050] With reference to FIG. 7, the auxetic membrane or mesh 25 may be secured to the back frame structure 28 utilizing a plurality of threaded fasteners 52 that extend through openings 54 of edge band 36. Threaded fasteners 52 engage threaded openings 56 in back frame structure 28. Threaded openings 56 may comprise threaded inserts or other suitable arrangement. As discussed above, the back frame structure 28 may comprise a polymer material (e.g. molded polypropylene). Alternatively, the back frame structure 28 may comprise metal (e.g. steel) or other suitable material.

[0051] With further reference to FIG. 8, the auxetic membrane or mesh 25 may also be secured to the back frame structure 28 utilizing an integrally formed flange 58 that is received in a channel or groove 60 of back frame structure 28. Alternatively, as shown in FIG. 9, auxetic membrane or mesh 25 may include a flange 58A that is received in a channel or groove 60 of back frame structure 28, and threaded fasteners 52A may be utilized to rigidly interconnect the auxetic membrane 25 to the back frame structure 28.

[0052] Still further, with further reference to FIG. 10, the back frame structure 28 may comprise tubular structures 62, and auxetic membrane 25 may include an edge portion 64 that is hook or J-shaped to extend around the tubular member 62. The tubular member 62 may comprise steel tubing or other suitable material.

[0053] Still further, with reference to FIG. 11, the auxetic membrane or mesh 25 may include an integrally-formed end portion 66 that is molded around a tubular reinforcing member 68 of back frame structure 28. The tubular inner reinforcing member 68 is optional, and the integral end portions 66 may comprise polymer tubular portions that are integrally formed with the auxetic membrane or mesh 25. Alternatively, end portions 66 may comprise solid polymer material (e.g. polypropylene) that is integrally formed (e.g. molded) with auxetic mesh/membrane 25.

[0054] With further reference to FIG. 12, an auxetic mesh material 70 according to another aspect of the present invention includes a plurality of first auxetic cells 72A and second auxetic cells 72B that are joined together along an intersection line 74. The auxetic cells 72A are oriented such that a force acting in a first direction (i.e. along the Y axis) causes the auxetic cells 72A to expand in a second, transverse direction (i.e. in the direction of the X axis). However, the auxetic cells 72B are oriented such that a force acting in the direction of the X axis causes the auxetic cells 72B to expand in the direction of the Y axis. The auxetic mesh or material 70 may be utilized to provide increased compliance and/or other properties in the high pressure regions 44 or 48. Furthermore, the sizes of the auxetic cells 72A and/or 72B may be varied, and/or the dimensions of the individual links 40A-40F forming the auxetic cells 72A and 72B may be varied to provide increased or decreased compliance/flexibility in specific regions as required.

[0055] With further reference to FIGS. 13 and 14, an auxetic mesh or membrane 75 according to another aspect of the present invention includes a circular auxetic pattern formed by a plurality of auxetic “bowtie” cells 76 that extend about/around a center 78 to provide a plurality of concentric rings 80A-80E extending about center 78. The auxetic mesh 75 may include transition zones or regions 82A-82C (FIG. 14) that transition from a generally circular auxetic center region 86 and a rectangular or quadrilateral perimeter 84. A circular auxetic mesh 75 may be utilized in the high pressure regions 44 and/or 48 to provide increased compliance. The perimeter 84 (FIG. 14) may comprise a transition to a “linear” auxetic pattern such as the auxetic cells 72A and/or 72B (FIG. 12). The thickness of the individual links 40 forming the auxetic mesh 75 may be increased or decreased to provide increased compliance/flexibility.

[0056] With further reference to FIGS. 15 and 16, a circular auxetic material or mesh 90 according to another aspect of the present invention includes a plurality of auxetic cells 92 that are arranged in a circular pattern about a center 94. The circular auxetic region 90 may include a rectangular perimeter 96 that forms a transition to one or more linear auxetic regions 98A-98D. The radial auxetic pattern 90 may be positioned at a high pressure region 44 or 48 to provide increased compliance. The thickness of the individual links 40 forming the auxetic cells 92 may be varied to provide increased flexibility/compliance in high pressure regions 44 and 48. The individual auxetic cells 92 of the radial auxetic pattern 90 have a “bowtie shape” wherein the individual auxetic cells 92 are arranged to extend radially outwardly from center 94 in a manner that is somewhat similar to the spokes of a wheel. In contrast, as noted above, the auxetic cells 76 of the auxetic mesh 75 (FIG. 13) extend around center 78 to form concentric ring-like patterns or structures.

[0057] The auxetic patterns of FIGS. 12-16 may be utilized to form auxetic user supports in the chairs of FIGS. 1-11

described above and/or the chairs of FIGS. 17-21 described below. Also, the auxetic patterns of FIGS. 12-16 may be utilized in virtually any user support structure such as seating units, cots, folding chairs, etc.

[0058] With further reference to FIG. 17, a chair 1B according to another aspect of the present invention includes a molded polymer shell structure 100 having a seat portion 104 and a back portion 106 having an auxetic mesh portion 125. The molded shell structure 100 may be mounted to a base 102 having a plurality of rollers 110A-110B. The auxetic mesh 125 may be integrally formed with the molded shell structure 100, and it may include a plurality of individual auxetic cells 138. The auxetic cells 138 may be configured in various ways as discussed in more detail above in connection with FIGS. 1-16. The shell structure 100, including auxetic mesh 125, may be molded from polypropylene or other suitable polymer material. The seat portion 104 may also include an auxetic mesh 125. As shown in FIG. 18, the back 106 may include an integral frame structure 128 extending around the auxetic mesh material 125. It will be understood that the thickness of the auxetic mesh material 125 may vary to provide increased compliance in areas of the back 106 that tend to be subject to higher pressures or forces in use. The shell structure 100 may also be supported by a plurality of legs 130A-130D as shown in FIG. 19 to form a chair 1C according to another aspect of the present invention.

[0059] With further reference to FIGS. 20 and 21, a chair 1D according to another aspect of the present invention includes a seat 134 and a back 136. The seat 1D includes a structure 138 that is supported on a base 2A. The chair 1D may include armrests 114A and 114B. Chair 1D includes a back frame 140 having upwardly extending side frame portions 142A and 142B. The back frame 140 also includes a horizontal upper portion or member 144 and a lower portion 146. The upper and lower portions 144 and 146 extend between and interconnect the upright portions 142A and 142B to form a central opening 148. An auxetic mesh 150 includes opposite edge portions 152A and 152B that are connected to the upright side frame portions 142A and 142B, respectively. Upper edge portion 154 of auxetic mesh or membrane 152 is spaced apart from the upper horizontal frame portion 144 to define a gap 156. Lower edge 158 of auxetic mesh or membrane 150 may be spaced apart from lower frame portion 146 to form a gap 160. The auxetic mesh or membrane 150 may include a plurality of individual auxetic cells 162 that are oriented as shown in FIGS. 20 and 21. Alternatively, the auxetic mesh 150 may include auxetic cells that extend side-to-side and/or radial or circumferential auxetic cells as described in more detail above in connection with FIGS. 13-16. Furthermore, the auxetic cells of auxetic material 150 may be oriented in different directions as shown in FIG. 12. In this way, the flexibility/compliance of the back 136 can be varied to provide increased flexibility/compliance in high pressure regions as required to provide improved user comfort.

[0060] With further reference to FIG. 22, a user support 165 according to another aspect of the present invention includes a frame 167 having a central opening 168 and a mesh or membrane 170 extending across the opening 168. In the illustrated example, the user support 165 comprises a seat having a construction that is somewhat similar to the seat 4A of FIGS. 5 and 6. However, the user support 165 may also comprise a back support, or other type of user support surface.

[0061] The mesh or membrane 170 includes an edge portion 172 that may comprise solid sheet-like material of substantially uniform thickness having an outer edge 174 that is received within a recessed region of frame 167 to provide a smooth upper surface. The mesh or membrane 170 also includes a plurality of auxetic cells 186 having a border 173 where the auxetic cells 186 transition to the solid edge portion 172. The regions of mesh or membrane 170 inside of the edge or border 173 have increased compliance or flexibility relative to the solid edge portion 172. The mesh or membrane 170 may be mounted to frame 167 as shown in FIGS. 7-11, or utilized in other suitable arrangements. The edge portion 172 may have substantially uniform thickness, and may include regions or areas 178A-178E having increased width to provide increased bending stiffness. The edge portion 172 may also include regions or areas 180A-180D wherein the edge portion 172 is narrower to provide increased flexibility due to the proximate location of the auxetic pattern or mesh 182 relative to the outer edge 174 of mesh or membrane 170. The mesh or membrane 170 may comprise a one-piece molded polymer member that is molded from polypropylene or other suitable material.

[0062] The mesh or membrane 170 includes high pressure zones or regions 184A and 184B. The individual links forming the auxetic cells 186A within the high pressure areas 184A and 184B have reduced thickness and/or width relative to the auxetic cells 186B outside of the high pressure zones or areas 184A and 184B. In the illustrated example, the high pressure zones or areas 184A and 184B generally correspond to the tuberosity of the ischium (buttocks) of a seated user. The mesh or membrane 170 also includes auxetic cells or patterns 186C and 186D that extend forwardly towards a front edge 188 of the user support 165. The auxetic cells 186C and 186D provide increased flexibility/compliance in the region of a user's thighs.

[0063] The user support 165 may further include elongated high pressure zones 184C and 184D corresponding to a user's thighs. The high pressure zones 184C and 184D may also include auxetic cells in which the width and/or thickness of the individual links forming the cells is reduced to provide increased compliance and user comfort. A central region or area 190 may include auxetic cells in which the individual links have increased width and/or thickness to provide additional stiffness. As discussed above, the shape and/or size of the high pressure zones of a particular user support 165 may be configured as required to provide user comfort. In general, pressure maps (not shown) may be developed utilizing a solid sheet of material, and the pressure maps may be utilized to provide varying degrees of compliance/flexibility. Also, the user support 165 may utilize auxetic cells having variable geometries as discussed above in connection with FIGS. 12-16. Furthermore, the frame 167 and mesh or membrane 170 may comprise a one-piece molded structure.

[0064] An auxetic membrane 112 according to another aspect of the present invention is shown in FIGS. 23-25. The auxetic membrane 112 includes a plurality of generally flat pads or user support surfaces 114 that are interconnected by a plurality of folded regions or webs 116 that includes hinges or fold lines. The auxetic membrane 112 expands in two directions (i.e. the X and Y directions) when stretched to shift from the contracted configuration shown in FIG. 24 to the expanded configuration shown in FIG. 23. The auxetic membrane 112 may comprise a polymer material (e.g. polypropylene) having substantially uniform thickness that is initially

molded into the contracted configuration of FIG. 24. Alternatively, auxetic membrane 112 may have variable thicknesses as discussed below in connection with FIG. 29. The auxetic membrane 112 may be attached or integrally molded to a perimeter frame as discussed above in connection with FIGS. 1-22.

[0065] An auxetic membrane 118 according to another aspect of the present invention is shown in FIGS. 26-29. The auxetic membrane 118 includes plurality of substantially flat pads or user support surfaces 120 that are interconnected by a plurality of webs or folded regions 122 having fold lines or hinges 123. The auxetic membrane 118 may be molded from polymer material (e.g. polypropylene) in a contracted configuration as shown in FIG. 27. The auxetic membrane 118 may be secured to a frame or it may include an integrally molded frame as discussed in more detail above in connection with FIGS. 1-22. In use, a user applies an out of plane force to the pads 120, thereby causing the auxetic membrane 118 to expand from the collapsed or contracted configuration of FIG. 27 towards the expanded configuration of FIG. 26.

[0066] With reference to FIG. 29, the flat pad portions 120 of auxetic membrane 118 may have a thickness "T1" that is significantly greater than the thickness "T2" of the folding web portions 122. The auxetic membrane 118 may include a plurality of integrally formed (e.g. molded) linear grooves 123A and 123B having reduced thickness to form living hinges/fold lines 123. Auxetic membrane 118 may be molded such that it assumes the three dimensional shape shown in FIG. 29 unless forces are applied to flex webs 122 to form the expanded shape/configuration 122A. The thickness of the webs 122 and/or the thickness of linear grooves 123A and/or 123B may vary in different regions of the auxetic membrane 118 to provide varying compliance/flexibility. For example, the thickness of webs 122 and/or grooves 123A and/or 123B may be reduced in high pressure regions 44 and/or 48 (FIG. 2) or region 44A (FIG. 4A). Thus, in contrast to folded paper/origami arrangements, the auxetic membrane 118 may comprise a molded polymer structure having variations in thickness and a preformed three dimensional ("3D") shape that provides specific predefined compliance/flexibility as required for a particular user support or region within a user support.

[0067] The auxetic membrane 112 (FIGS. 23-25) may include thicker pads/flat portions 114 and reduced thickness webs 116 that are similar to the flat pad portions 120 and webs 122, respectively, of FIG. 29. The auxetic membrane 112 may also include grooves forming fold lines 117 that are substantially similar to the grooves 123A and 123B of FIG. 29. The pads/support surfaces 114 and 120 of auxetic membranes 112 and 118, respectively, form side faces (e.g. side face 120A, FIG. 29) that are contacted by a user.

[0068] The auxetic membrane 112 of FIGS. 23-25 and the auxetic membrane 118 of FIGS. 26-28 may be initially secured to a perimeter frame in a collapsed or contracted configuration as shown in FIGS. 24 and 27, respectively. Alternatively, the auxetic membranes 112 and 118 may be secured to a perimeter frame in a partially expanded configuration that is between the retracted configurations of FIGS. 24 and 27 and the fully expanded configurations of FIGS. 23 and 26. The fully expanded configurations of FIGS. 23 and 26 correspond to a flat sheet of material, and the lines in FIGS. 23 and 26 represent fold lines.

[0069] With further reference to FIGS. 30 and 31, an auxetic membrane 192 according to another aspect of the present

invention includes a plurality of center pads or “star” portions **194** with radial or spiral links **196** interconnecting adjacent star portions **194**. The links **196** form a plurality apertures or openings **198** between links **196**. The auxetic membrane **192** expands in both the X and Y directions if stretched in either the X or Y direction. The auxetic membrane **192** may be connected to a frame member of a chair or other seating unit as discussed in more detail above in connection with FIGS. 1-22.

[0070] With further reference to FIG. 31, the pads/center portions **194** of auxetic membrane **192** may comprise circular raised areas having an increased thickness “T3” relative to a thickness “T4” of web portions/links **196**. The pads **194** form a side face **194A** of auxetic membrane **192**. In use, a user contacts the side face **194A** formed by the center portions **194** without contacting the links **196**.

[0071] It will be understood that the features of the different embodiments shown and described in connection with FIGS. 1-21 are not necessarily mutually exclusive. For example, the chair **1D** of FIGS. 21 and 22 could include an auxetic mesh or membrane **25B** (FIG. 6) and/or the chair **1** (FIG. 1) could include a back frame structure **140** as shown in FIGS. 20 and 21.

[0072] The auxetic mesh/membrane of the present invention may be utilized in connection with a variety of user support surfaces, including generally upright back supports, generally horizontal seat supports, and in other support structures.

[0073] Also, the auxetic user support surfaces/membranes of the present invention may be utilized in connection with various seating units and articles of furniture in addition to the chairs of FIGS. 1-21. For example, the auxetic mesh could comprise a user support for vehicle seats, seats utilized in stadiums, aircraft seating, seating utilized in boats or other watercraft, benches, beds, folding chairs or cots, or virtually any other article having a support surface that contacts a user.

[0074] It is also to be understood that variations and modifications can be made on the aforementioned structures and methods without departing from the concepts of the present invention, and further it is to be understood that such concepts are intended to be covered by the following claims unless these claims by their language expressly state otherwise.

The invention claimed is:

1. A seating unit comprising:

a lower portion that is configured to support the seating unit;

a seating structure supported by the lower portion, wherein the seating structure includes a generally horizontal seat portion and a generally upright back portion, wherein at least one of the seat portion and the back portion includes frame portions defining a space therebetween and a flexible polymer membrane extending in first and second directions across the space, and wherein the polymer membrane is connected to the frame portions to define a user support surface, wherein at least a portion of the polymer membrane comprises an auxetic material having a negative Poisson's ratio whereby stretching of the auxetic portion of the polymer membrane in at least one of the first and second directions tends to cause the polymer membrane to expand in the other of the first and second directions.

2. The seating unit of claim 1, wherein:

the user support surface defines opposite edge portions adjacent to the frame portions, and at least one high

pressure region that is spaced apart from the opposite edge portions, and wherein the polymer membrane is significantly more flexible at the high pressure region than it is at the opposite edge portions of the user support surface.

3. The seating unit of claim 2, wherein:

the polymer membrane defines a region outside of the high pressure region having a first thickness, and a second thickness in the high pressure region that is significantly less than the first thickness.

4. The seating unit of claim 2, wherein:

the polymer membrane comprises a polymer mesh having a plurality of links that are interconnected to form a pattern extending radially outwardly in a plurality of radial directions from a central portion of the high pressure region, and wherein stretching of the polymer mesh in the radial directions or in directions transverse to the radial directions tends to cause expansion of the polymer mesh in the other of the radial directions and the directions that are transverse to the radial directions.

5. The seating unit of claim 2, wherein:

the polymer membrane comprises a mesh having a plurality of links that are interconnected to form a pattern, and wherein the pattern is non-uniform to provide increased flexibility in the high pressure region.

6. The seating unit of claim 1, wherein:

the polymer membrane comprises a mesh having a central portion including a plurality of openings defining a plurality of auxetic cells;

the polymer membrane includes an integral ring having an outer perimeter and an inner boundary adjacent outermost ones of the openings defining the auxetic cells, wherein the ring defines a width between the outer perimeter and the inner boundary, and wherein the width is non-uniform.

7. The seating unit of claim 1, wherein:

the flexible polymer membrane comprises polypropylene.

8. The seating unit of claim 1, wherein:

the frame portions comprise polymer material that is integrally formed with the polymer membrane, and wherein the frame portions are significantly thicker than the polymer membrane and have significantly greater stiffness than the polymer membrane.

9. The seating unit of claim 1, wherein:

the frame portions are generally upright to define a back frame;

the back frame includes transverse upper and lower frame portions extending between and interconnecting the upright frame portions to form a perimeter frame defining a central opening; and wherein:

the flexible polymer membrane includes an upper edge that is spaced apart from the upper frame portion to define a gap therebetween.

10. The seating unit of claim 1, wherein:

the frame portions include first connecting structures; and wherein:

the flexible polymer membrane includes integrally formed second connecting structures that engage the first connecting structures and connect the polymer membrane to the frame portions.

11. The seating unit of claim 1, wherein:

the polymer membrane defines a user support face comprising a plurality of spaced apart support members that

are interconnected by folded sheet portions configured to provide an auxetic material.

12. A user support structure comprising:

a flexible membrane defining front and rear faces and opposite edge portions, the flexible membrane including a high pressure region that is configured to support portions of a user's body when a user's body comes into contact with the high pressure region of the flexible membrane, the flexible membrane defining a lower pressure region adjacent the high pressure region, and wherein the high pressure region and the lower pressure region comprise auxetic material whereby stretching of the flexible membrane in a first direction tends to cause the material to expand in a second direction that is transverse to the first direction and wherein the flexible membrane is significantly more compliant in the high pressure region than the lower pressure region in response to a force that is applied to the front face of the flexible membrane.

13. The user support structure of claim 12, including:

a pair of spaced apart frame portions extending along the opposite edge portions of the flexible membrane, and wherein the opposite edge portions of the membrane are connected to the frame portions.

14. The user support structure of claim 13, wherein:

the frame portions extend horizontally and at least a portion of the front face of the flexible membrane faces upwardly to define a seat surface.

15. The user support structure of claim 13, wherein: the frame portions extend upwardly and at least a portion of the front face of the flexible membrane faces forwardly to define a back support surface.

16. The user support structure of claim 12, wherein: the flexible membrane comprises a polymer mesh.

17. The user support structure of claim 16, wherein: the flexible membrane comprises an integrally formed polymer ring defining an outer peripheral edge of the flexible membrane.

18. The user support structure of claim 12, wherein: the flexible membrane comprises a plurality of spaced apart support members that are interconnected by folded sheet portions configured to provide an auxetic material.

19. A user support comprising:

a polymer mesh including a plurality of links forming interconnected auxetic cells, each auxetic cell having a length defined along a first cell axis and a width defined along a second cell axis that is transverse to the first cell axis, and wherein each auxetic cell comprises a plurality of interconnected flexible links configured such that stretching of the auxetic cells along the length of the auxetic cells causes the width of the auxetic cells to increase, and wherein a plurality of the auxetic cells are arranged about a center in a generally circular pattern to provide a region having increased compliance.

20. The user support of claim 19, wherein:

the polymer mesh comprises polypropylene.

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