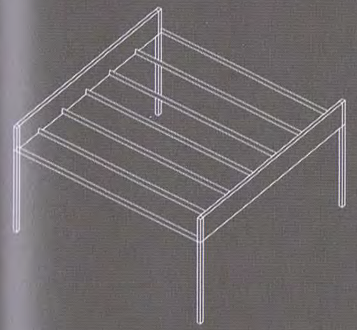
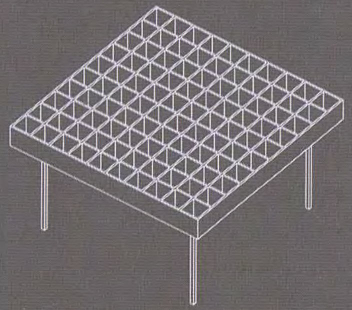
Frames and grids are structural systems composed of linear elements that distribute loads in a linear pattern. Frames are composed of columns and beams, in the form of portals, that provide paths for the distribution of loads. Frames can be built of steel, or in combinations of steel and reinforced concrete. In cases where steel and reinforced concrete are combined, the beams are usually steel and the reinforced concrete is a secondary slab, cast insitu, of either lightweight concrete on metal decking or precast concrete with an insitu topping spanning between the steel beams. Where the frame and the slab are built entirely of reinforced concrete a number of alternatives are available: one-way reinforced concrete slabs on beams spanning one way (most appropriate for rectangular grids with an aspect ratio of 2:1 or greater); two-way, reinforced-concrete slabs spanning to two-way-spanning beams (gives lower self weight and therefore longer spanning capability on square grids with an aspect ratio between 1:1 and 2:1) and a two-way-spanning, reinforced-concrete, flat slab spanning onto columns (most economical in terms of formwork and results in minimum depth of structure and minimized story height on square grids with an aspect ratio of less than 2:1). System considerations have not specifically addressed resistance to lateral loads.

One-way frames, built of steel, timber, or reinforced concrete, direct the primary bending moments along a single axis running the length of a beam resting on two columns at either end. These primary portals stand parallel to one another, with a smaller secondary set of beams spanning between them at closer centers. Slabs can be added to the frame, and they can be designed to act independently or, with the addition of studs, channels or shear connectors, compositely with the supporting beams. In one case the slab spans the short distance, while in the other the compositely acting slab and beam provide the support.
Two-way frames direct the primary bending moments along two axes, laterally and longitudinally, in the form of a grid of beams spanning a set of columns.
Diagrids are single-layer grids constructed from elements which can be made of diagonal steel, steel-reinforced concrete, or lightweight timber beams that distribute axial loads across the lines of a diamond or triangulated grid. Loads are distributed regularly or irregularly, according to whether the angles that form the diamond geometry are regular or change along the surface of the grid. A diagrid – a grid with diagonal geometry – used in a vertical format can thus eliminate the need for large corner columns by providing lateral support, and produce shapes that are crystalline or smooth, for example in high-rise structures.
Grid shells are single-layer grids that distribute loads in two directions. They are constructed from a grid or a lattice, in wood or steel, composed of linear members such as tubes or solid members which are continuous, passing above and below each other at the nodes, or discontinuous, with bolted or welded connections. Grid-shells derive their strength from their double curvature, where two grids or lattices are combined to form a rigid shell, accommodating large spans and many shapes.
Space frames are double-layer grids that distribute loads in three directions. They are constructed from interlocking steel struts in a geometric pattern, often square, pentagonal or hexagonal, forming interlocking square pyramids or tetrahedral pyramids. These are composed of diagonal struts that join the upper and lower grids, and have either a single unit length or change the lengths of the struts to curve the overall structure or incorporate other geometrical shapes. Space frames transmit loads in tension and compression along the length of each strut, thereby uniting the two layers into one that has strength along the longitudinal, perpendicular, and diagonal axes. Accordingly, space frames are lightweight yet rigid and multidirectional, accommodating long spans and all types of shapes.

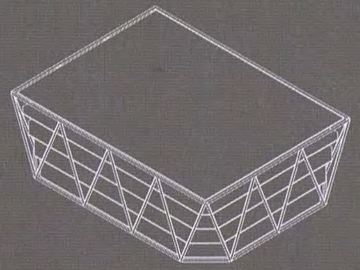
Grids and Frames



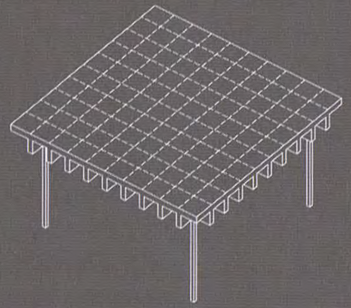
One-Way Frame



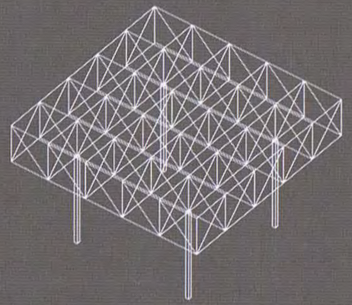
Two-Way Frame



Diagrid



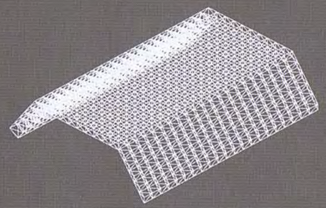
Grid-Slab



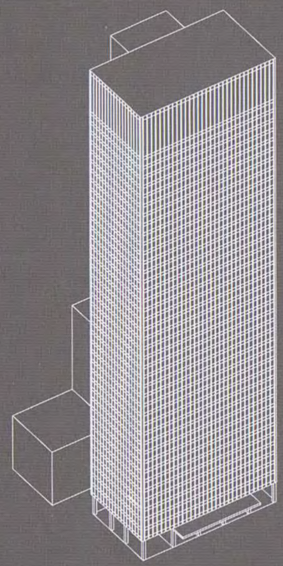
Double Layer Grid

Grids and frames tessellate along horizontal, vertical and curved axes of growth to produce horizontal, vertical or curved forms.

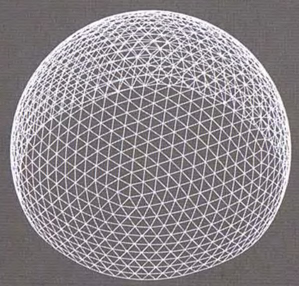
Horizontal tessellation can occur within any subsystem of grids and frames because the protogeometry of all such systems is capable of distributing loads along the horizontal axis. Horizontal tessellation results in shed-like forms that may vary in section and in ground plan or enclosing roof plan. Such variations are a result of changes in the grid or frame as it grows along the horizontal axis.
Vertical tessellation can occur within any system of diagrids, two-way frames, and grid-slab frames because they are all capable of distributing loads along more than one axis. The capacity to respond to bending moments in multiple axes is necessary in vertical forms where lateral forces and vertical loads have to be directed simultaneously.
The protogeometry of a diagrid is capable of vertical tessellation because the diagonal grid can distribute loads in both vertical and lateral (horizontal) directions. The vertical tessellation of diagrids can result in forms in which variations in the profile and surface geometry can be produced by changes in the scale of the diagrid or in the geometry of the enclosing plan along the vertical axis of growth.
The protogeometry of a two-way frame, in the form of a grid of beams resting on columns, enables it to grow both horizontally and vertically because of its capacity to stack vertically while responding to bending moments. Vertical tessellation of the two-way frame can result in forms that vary in profile, ranging from a regular extrusion to staggered vertical growth.
The protogeometry of a grid-slab frame, in the form of a slab and grid, enables it to grow both horizontally and vertically because of its capacity to stack vertically while distributing the bending moments in three directions (two of the directions within the gridded slab and a third one through the columns). However, the resulting vertical forms can vary in sectional and surface profile, from a symmetrical extruded structure to an asymmetrical faceted or smooth structure.
Curved tessellation can occur within all grid and frame subsystems, ranging from a regular array of portals, resulting in a dome, to the eccentric volumes with irregular curved profiles which can result from a diagrid, a two-way grid, a grid shell, or a three-way space frame. Curved tessellation produces irregular and differentiated forms which in some cases additional structural strength is found when the load-bearing lines of these frames approximate to structural catenaries, which are closer to arches or domes.
The protogeometry of a diagrid, a two-way grid, a grid shell and a grid slab can produce ruled or curved gridded surfaces with gradual and changing curvatures that distribute loads in a way that is similar to the distribution of loads in structural catenaries, arches or domes.
The protogeometry of a three-way space frame can produce curved forms with differing degrees of curvature by varying the orientation of the individual pyramidal cells.



Horizontal Tessellation



Vertical Tessellation

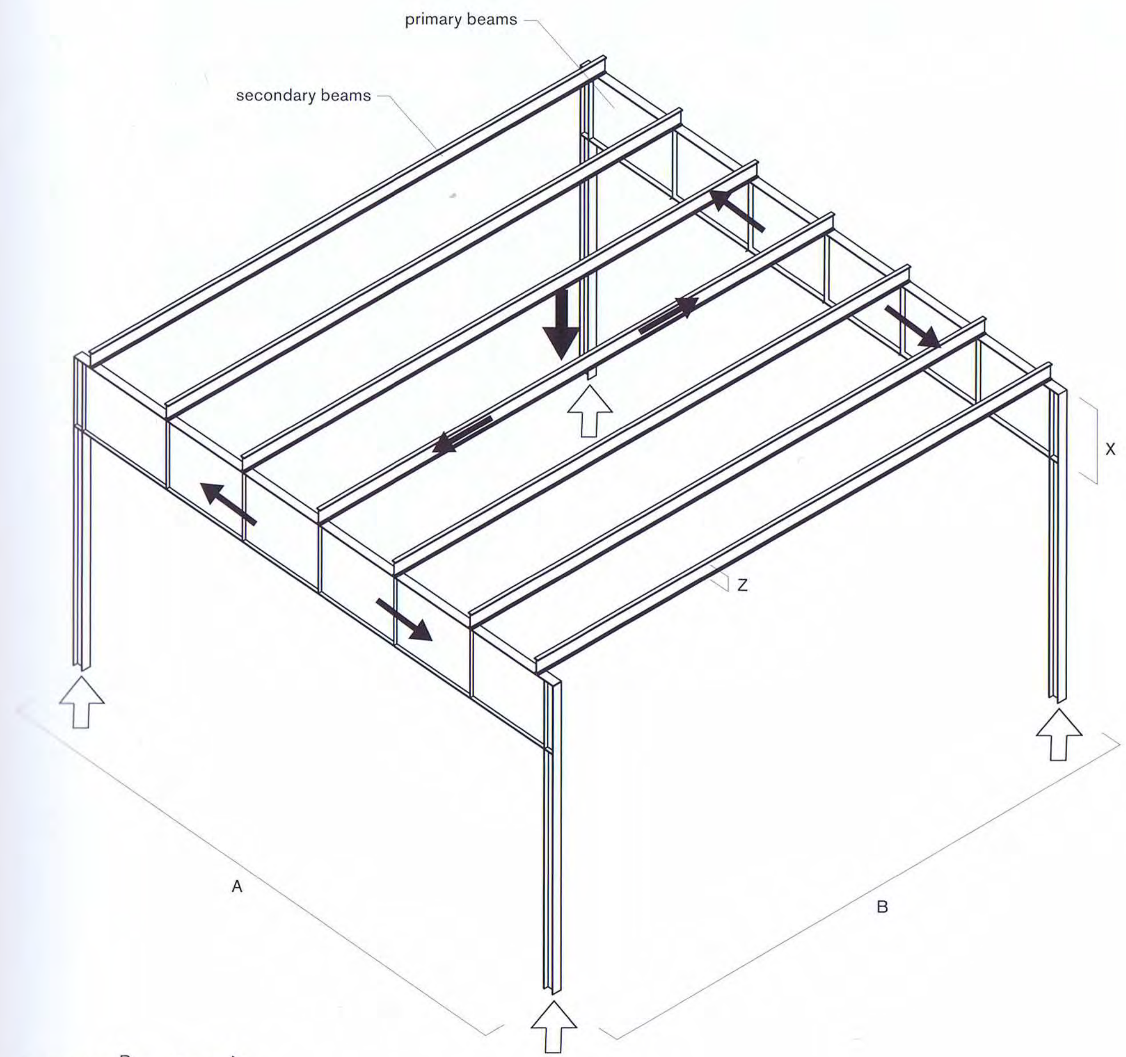


Curved Tessellation

One-Way Frame

The base unit of a one-way frame is composed of a rectangular grid of columns supporting a pair of primary, parallel beams along the column lines which in turn support secondary beams that span between them at much closer intervals than the centers of the columns. One-way frames direct the primary bending moments along the beam lines both primary and secondary. The loads travel from secondary to primary beams, and then to the columns. The purpose of using such a system is to cover the largest possible area with the most uniform and minimal depth of floor structure. This requires a balance between grid aspect ratio, structural depth of primary and secondary elements and the relative spans of each. For uniformity of floor depth the primary beam will usually span the shorter distance of a rectangular grid. This distribution of loads along the lines of the steel, concrete or wooden frame embeds the one-way frame with an optical affect of lightness and hierarchy that remains consistent within any space it defines.
The reflection of sound by a slab or surface that is supported by a frame can be modified by the characteristics of the frame. The degree to which the sound is modified corresponds to the degree of openness and lightness of the frame, and to the direction and spectrum of the sound. For example, a flat slab that would otherwise have an affect of specularity can, in conjunction with a frame, have one of diffusion. A frame together with its overlaid surfaces can have an affect of specularity, focusing or diffusion, depending on the degree of its openness and lightness, and the contours of the surfaces. A one-way frame usually modifies the reflection of sound by the supported slab or surface to a far greater extent if the sound is travelling orthogonally in relation to the frame than if it is travelling parallel to it.

The one-way frame is flexible in several ways:
Span: Because the protogeometry of a one-way frame is not fixed to an exact dimension but works with approximate depths to span ratios of 1:15~20, it allows for a range of spans from column to column. Accordingly, the base unit can produce a variety of plan forms in single structures by adopting different sizes of span.
Depth: The structural strength of the beam increases as the depth of its section increases. Increasing the depth of the beam therefore increases the rigidity of the system and allows for longer spans.
Flanges: When the frame is made of steel, the flanges of the beam as well as the depth of the web can be adjusted in scale in response to the loading requirements.
Profile: One-way frames can tessellate to produce forms that are horizontal (mats or sheds) or curved (domes). Because the base unit of the one-way frame can vary as it tessellates, it can allow for both regular and irregular profiles.
Affect: The affective properties of a one-way frame can be multiplied when the base unit imbricates or intertwines with external factors, such as asymmetries that respond to the physical constraints of the site, environmental considerations, programmatic requirements, etc. As a result, in addition to lightness and griddedness, a one-way frame can transmit other optical affects, including openness, freedom, segmentation, bending, porosity, orthogonality, diagonality, enclosure, rippling. A one-way frame can modify or dominate the acoustical affect of an overlaid surface by adding an affect of directional diffusion.



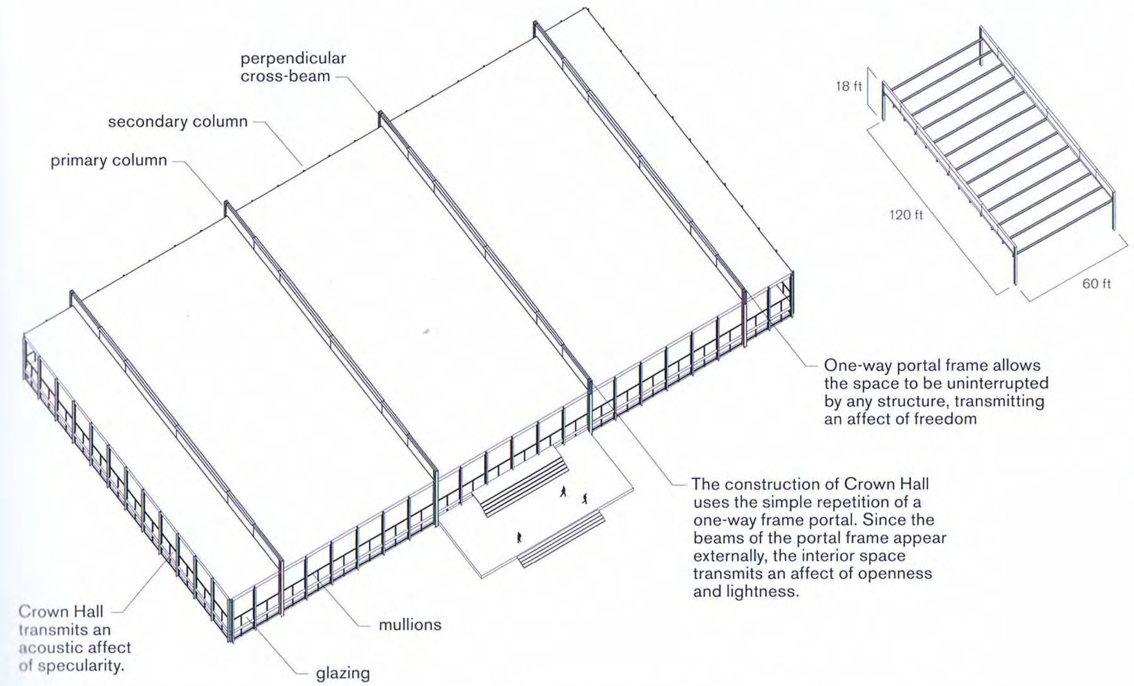
$Z =$ approx. $\frac{B}{20}$ $\quad X = \frac{A}{15\sim20}$

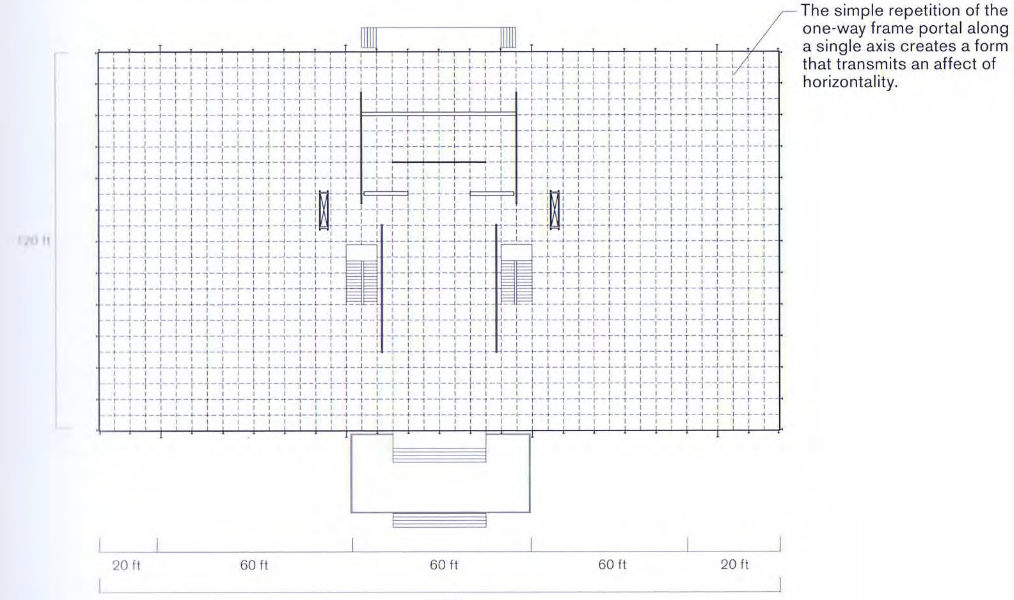
Ratios assume pin connections for the columns

Openness, Lightness, Freedom, Horizontality, Specularity

Horizontal / One-Way Frame

S.R. CROWN HALL, IIT | L. MIES VAN DER ROHE, PACE ASSOCIATES | CHICAGO, USA | 1950–56

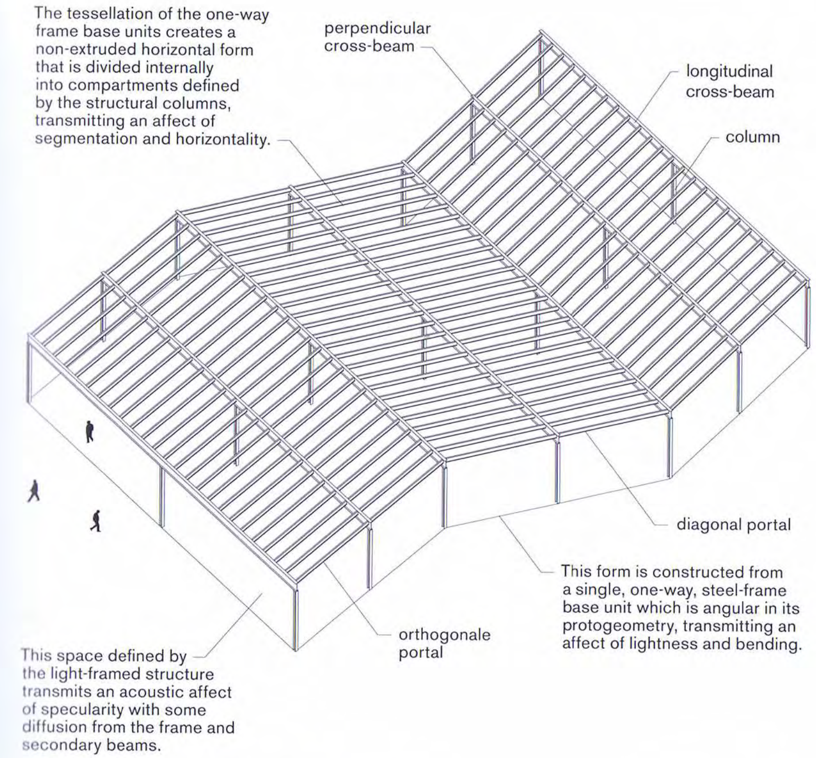


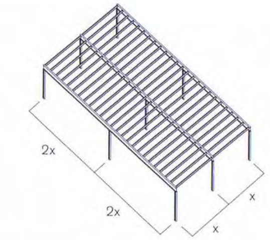


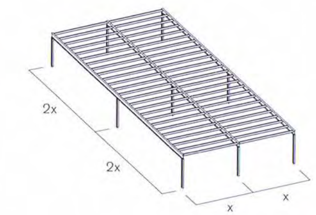
Crown Hall is formed by the tessellation of a one-way portal frame, utilizing three full bays and two smaller bays one-third of the width of the full bays. In this case the base unit varies in scale only, but variations in section are also possible by changing the height of the portals, which would change the profile of the resulting form. Crown Hall transmits an optical affect of orientation, lightness, freedom and horizontality. The acoustic affect of specularity is removed from the ceiling by the sound-absorbent suspended ceiling. The specularity of the glazing and other non-absorbent surfaces remains.

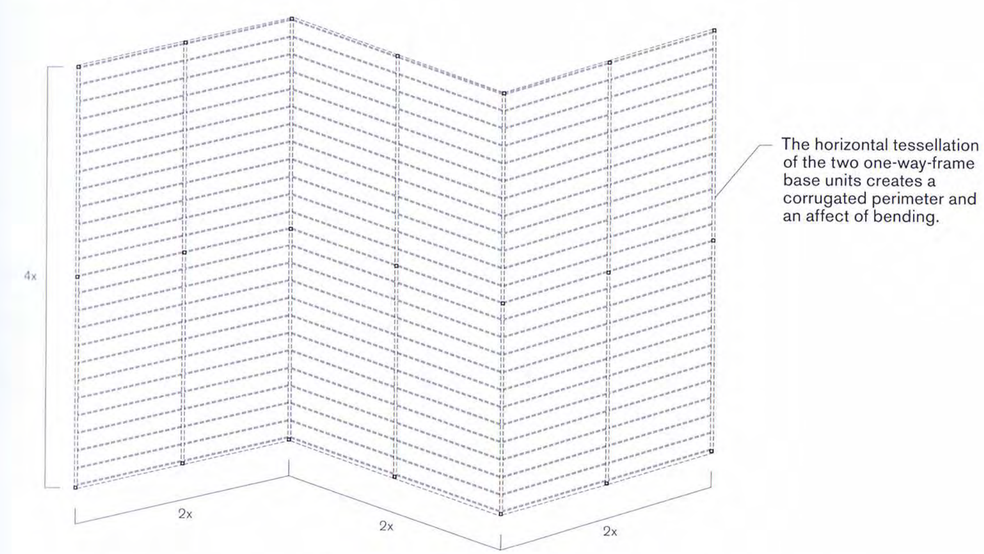
Segmentation, Lightness, Bending, Horizontality, Specularity

Horizontal / One-Way Frame





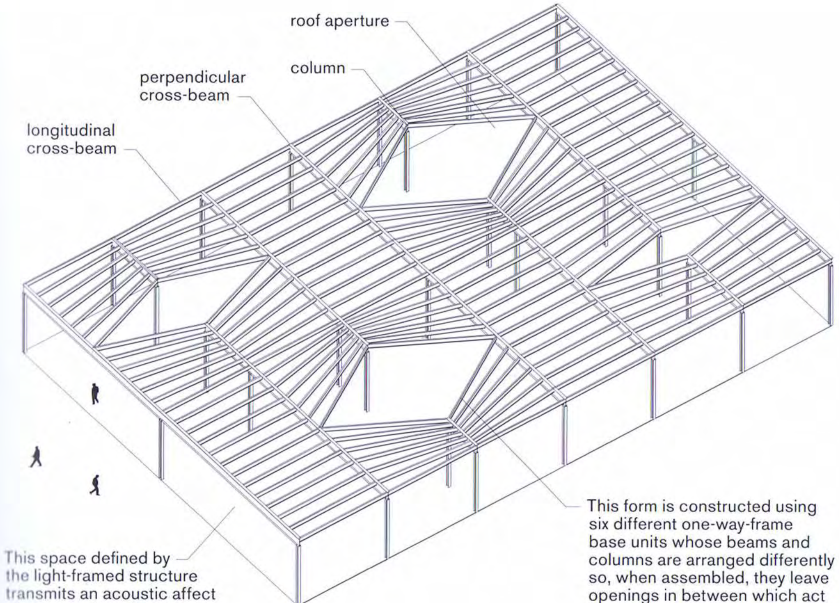




This horizontal form is produced by the tessellation of a one-way portal frame resting on columns at mid-span, with the one-way orthogonal portal varying, as it repeats, to become diagonal. The combination of orthogonal and diagonal portals changes both the external and the interior perimeter profiles of the space structure. This form of enclosure transmits an optical affect of segmentation, lightness, bending and horizontality, and an acoustical affect of specularity and some diffusion.

Porosity, Lightness, Horizontality, Specularity, Diffusion

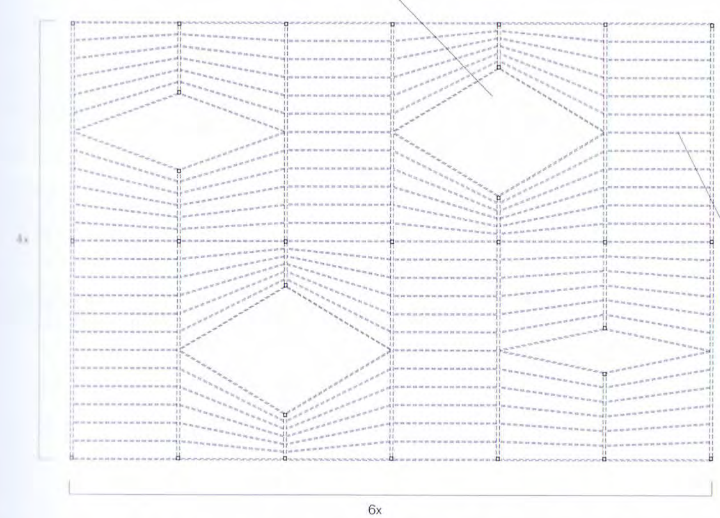
Horizontal / One-Way Frame



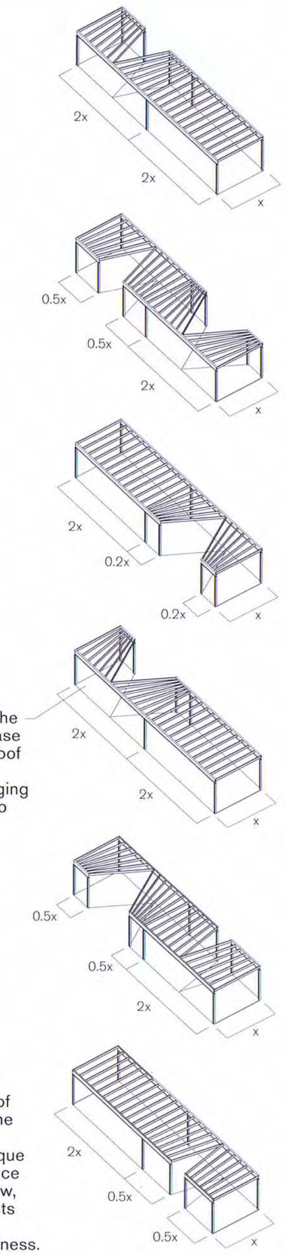
This space defined by the light-framed structure transmits an acoustic affect of specularity with some diffusion from the frame and secondary beams.

This form is constructed using six different one-way-frame base units whose beams and columns are arranged differently so, when assembled, they leave openings in between which act as skylights.

The number and size of the openings can vary and also be staggered across the bays of the frame.



The introduction of skylights within the orthogonal form establishes a unique horizontal reference to the space below, transmitting affects of horizontality, porosity and lightness.

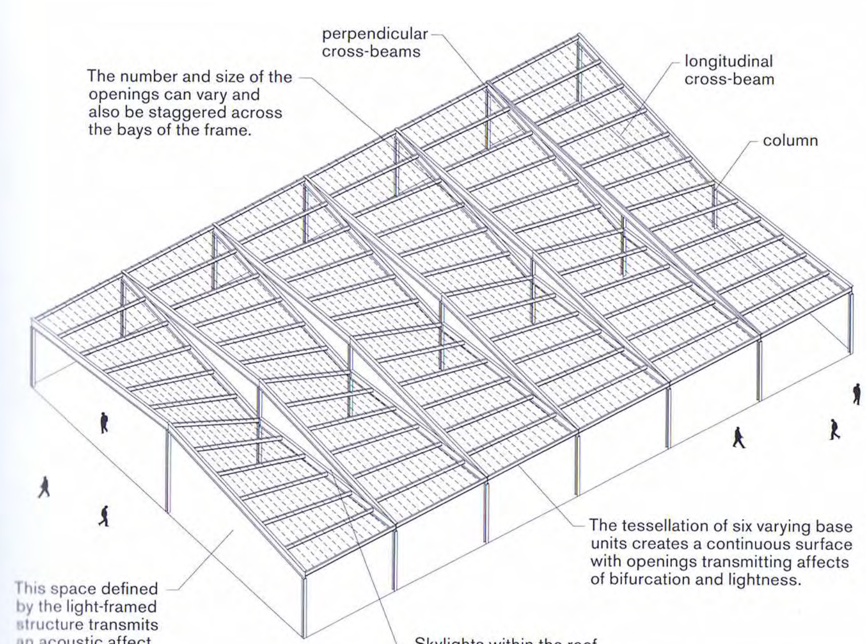


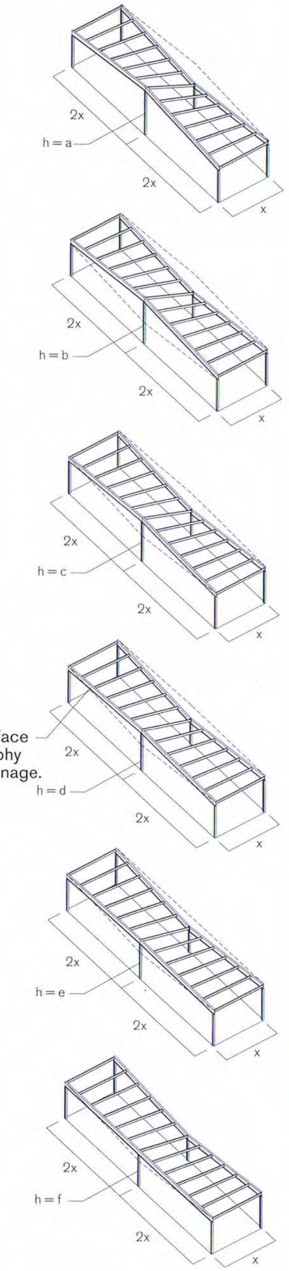
Variations in the position of the column and beam in each base unit create openings in the roof surface which can become skylights or courtyards, bringing natural light or ventilation into deep-plan shed forms.

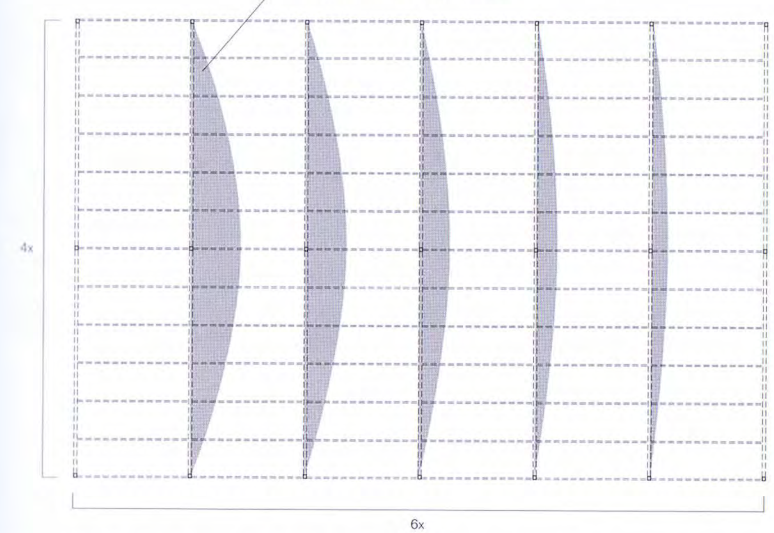
This horizontal form is produced by the tessellation of six different one-way-frame base units, introducing a staggered arrangement of supporting columns which results in the displacement of the secondary beams and openings on the roof surface. This form of enclosure transmits an optical affect of porosity, orthogonality, lightness and horizontality, and an acoustical affect of specularity and some diffusion.

Bifurcation, Lightness, Diagonality, Specularity

Horizontal / One-Way Frame



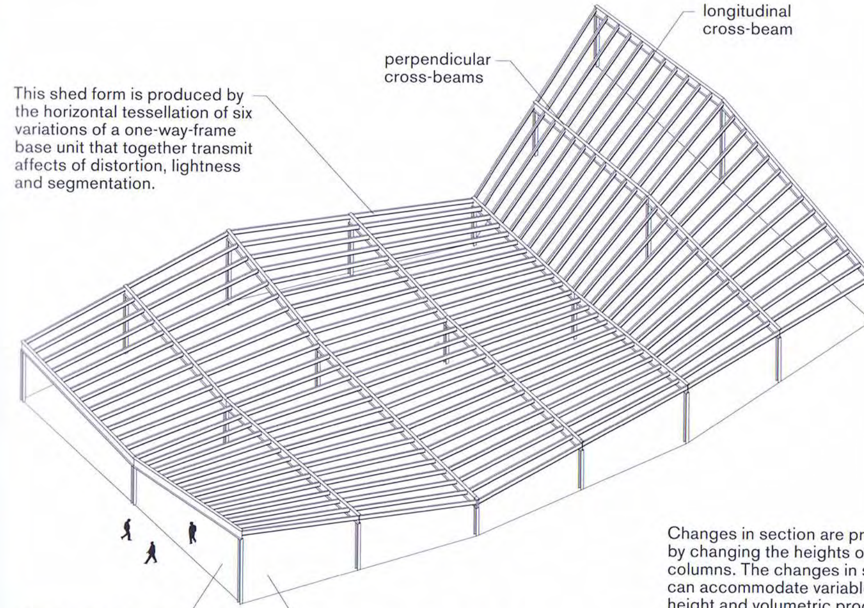


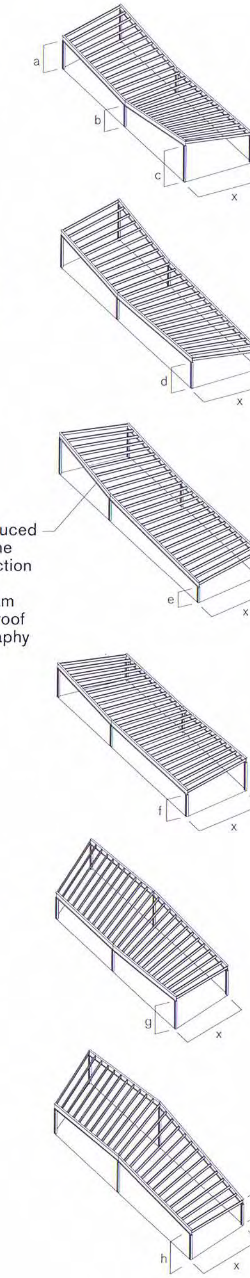


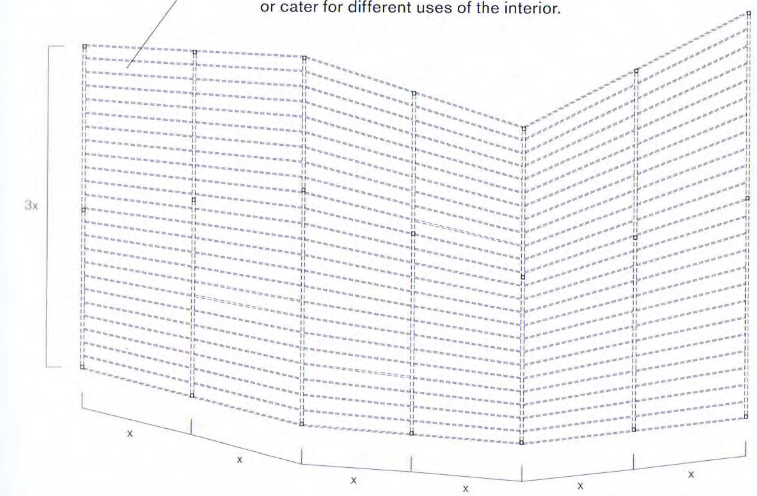
This horizontal form is produced by the tessellation of six different one-way-frame base units that vary in the height and profile of the portals. The tessellation of the six base units leaves gaps in the resulting roof surface that can introduce light in the interior, and a diagonal orientation within the space. This form of enclosure transmits an optical affect of bifurcation, lightness, and diagonality, and an acoustical affect of specularity.

Distortion, Lightness, Segmentation, Specularity, Diffusion

Horizontal / One-Way Frame





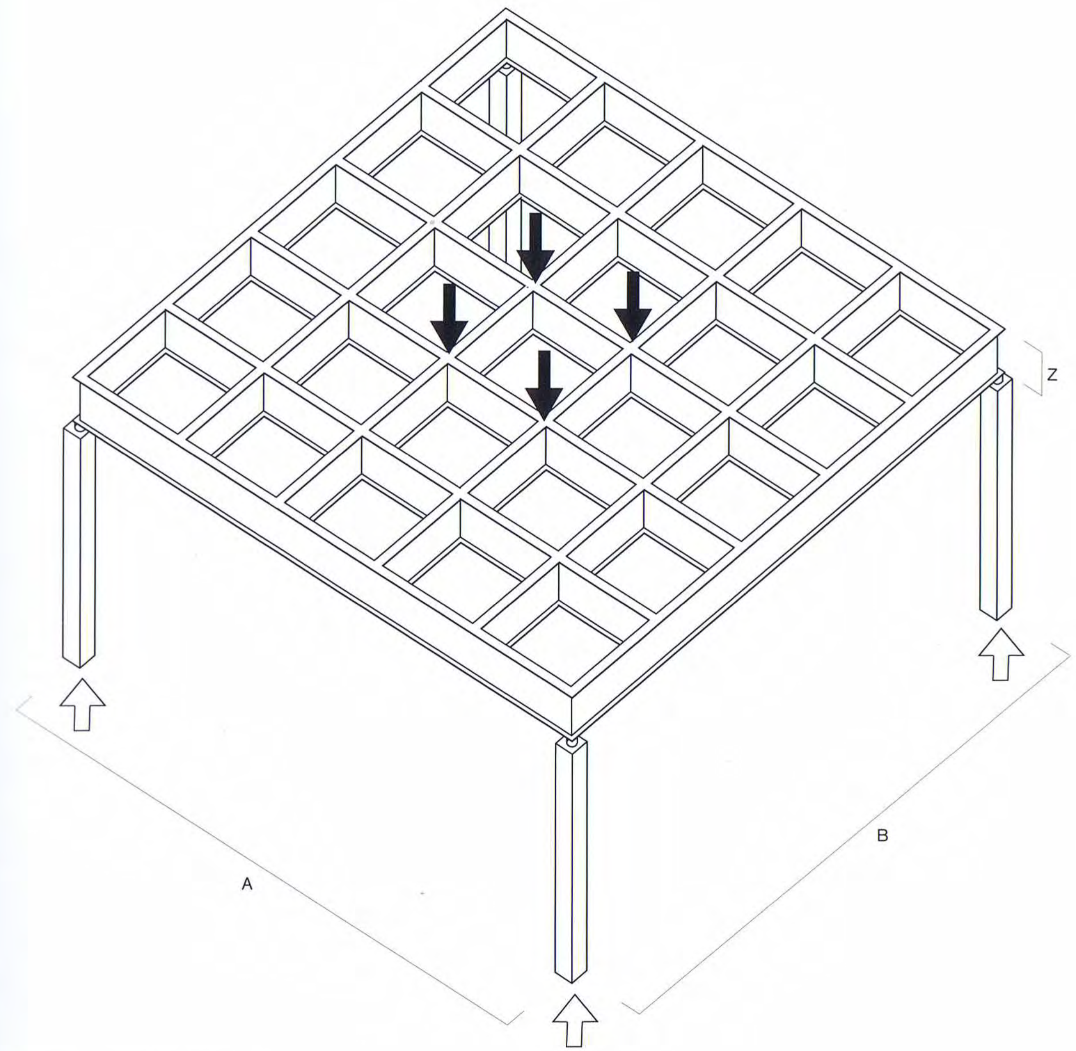


This horizontal form is produced by the tessellation of a one-way-frame portal base unit, with a number of portals changing in section as irregular changes are introduced to the overall height of the perimeter columns, varying the height of the interior space and the topography of the roof. This form of enclosure transmits an optical affect of distortion, lightness, and segmentation, and an acoustical affect of specularity with some diffusion.

The base unit of a two-way frame is composed of a lattice of beams resting on four or more columns. Bending moments in a two-way frame are distributed in two directions, producing a rigid structure. Two-way frames need to have an aspect ratio of 2:1 or less. The distribution of loads along lines of steel or laminated timber embeds the two-way frame with an optical affect of lightness and striation that remains consistent within all spaces it defines. The reflection of sound by a slab or surface that is supported by a frame can be modified by the characteristics of the frame. The degree to which the sound is modified corresponds to the degree of openness and lightness of the frame, and to the direction and spectrum of the sound. For example, a flat slab that would otherwise have an affect of specularity can, in conjunction with a frame, have one of diffusion. A frame together with its overlaid surfaces can have an affect of specularity, focusing or diffusion, depending on the degree of its openness and lightness, and the contours of the surfaces.

The two-way frame is flexible in several ways:
Span: As the protogeometry of the two-way frame is not fixed to an exact dimension but works with approximate depths to span ratios of 1:25-30 in a grillage, the frame can be thinner overall because it bridges from column to column. Accordingly, the base unit can use spans of different sizes to produce a variety of non-extruded plan forms in single structures.
Depth: The depth of the beam's web varies according to the size of the span, with the structural strength and stiffness of the beam increasing in proportion to the depth of its section.
Profile: Two-way frames can tessellate to produce horizontal forms (mats or sheds), or, when combined with steel-decked thin concrete slabs, they can be stacked to produce vertical forms (towers). As it tessellates, the base unit of a one-way frame can vary to allow for regular or irregular perimeters and profiles.
Affect: The affective properties of a two-way frame can be multiplied when the base unit imbricates or intertwines with external factors, such as asymmetries that respond to the physical constraints of the site, environmental considerations, programmatic concerns, etc. As a result, in addition to lightness and striation, a structure based on a two-way frame can transmit other optical affects, including boundlessness, repetition, differentiation, enclosure, centeredness, weightiness, extrusion, stacking, hinging, continuity. A two-way frame can modify or dominate the acoustical affect of the overlaid surface by adding an affect of diffusion.

Two-Way Frame



$$Z = \frac{\text{the greater of A or B}}{25 \sim 30}$$

A = B so then distribution is even

If A = 2B all loads go to A as loads follow shortest route

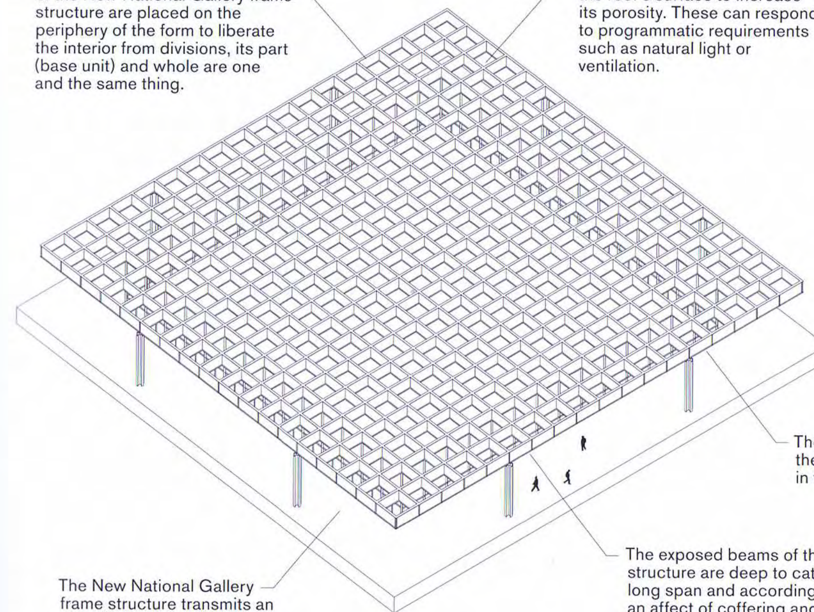
A = approx. (25–30) Z

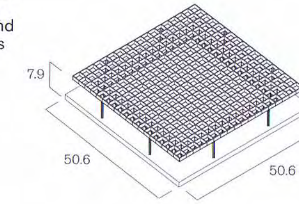
Span (A,B) to Depth (Z) Ratio = 1:25–30

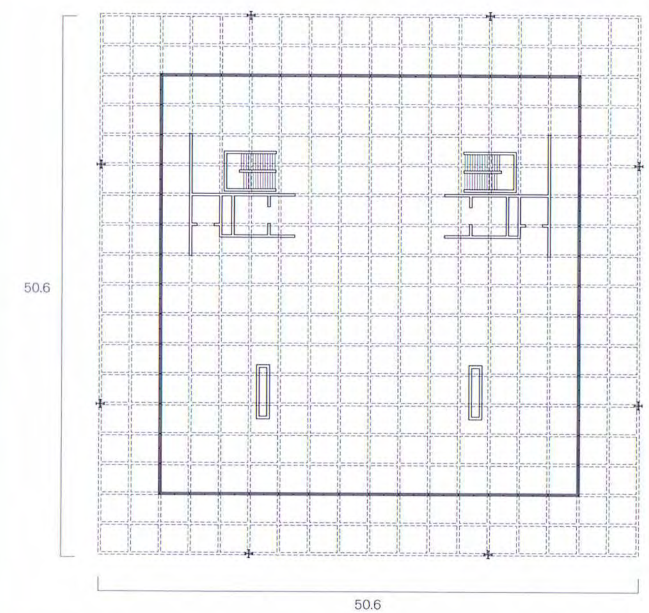
Openness, Coffering, Abstraction, Horizontality, Diffusion

Horizontal / Two-Way Frame

NEW NATIONAL GALLERY | L. MIES VAN DER ROHE | BERLIN, GERMANY | 1962–68



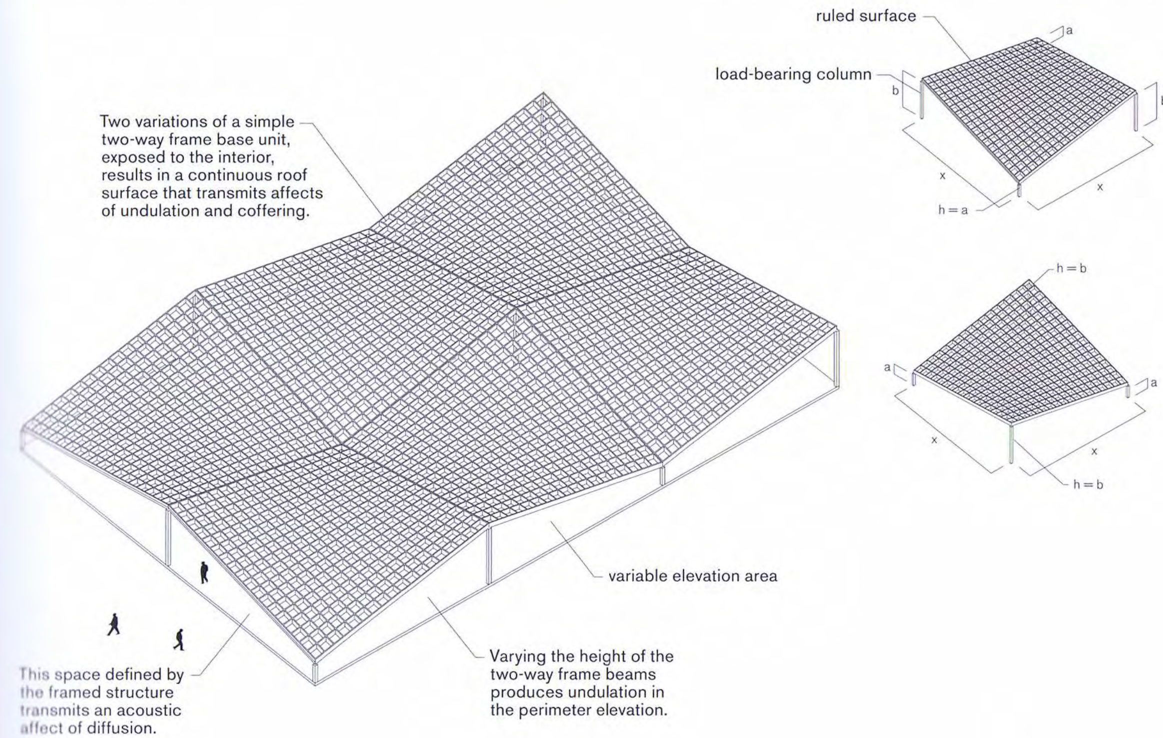


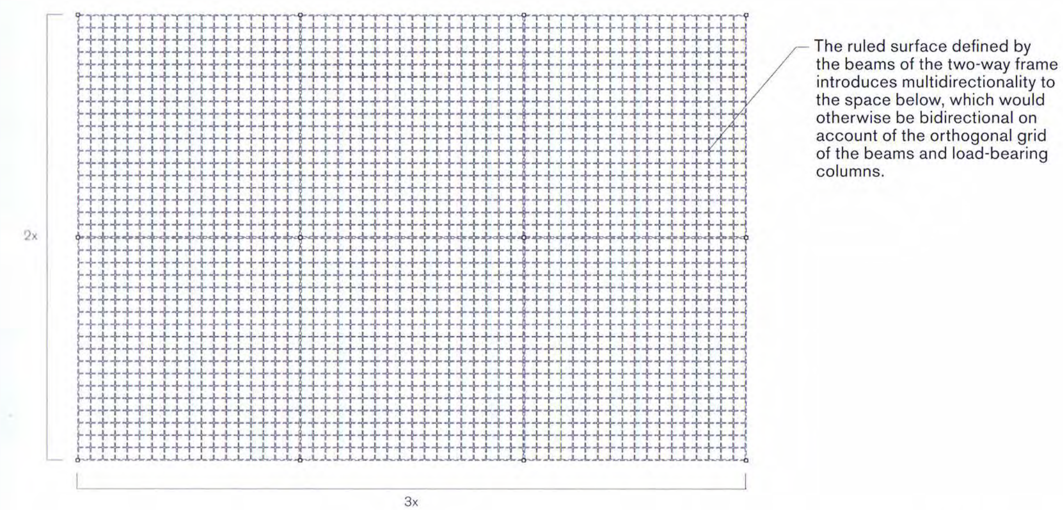


The New National Gallery is formed by the simple repetition of a regularly spaced two-way frame. In this case the base unit extends simply across the space, but this type of structure can be varied by changing the height of the columns or the depth of the beams, which would in turn vary the profile of the resulting form. The New National Gallery transmits an optical affect of openness, abstraction, horizontality and coffering, and an acoustical affect of diffusion.

Undulation, Coffering, Diffusion

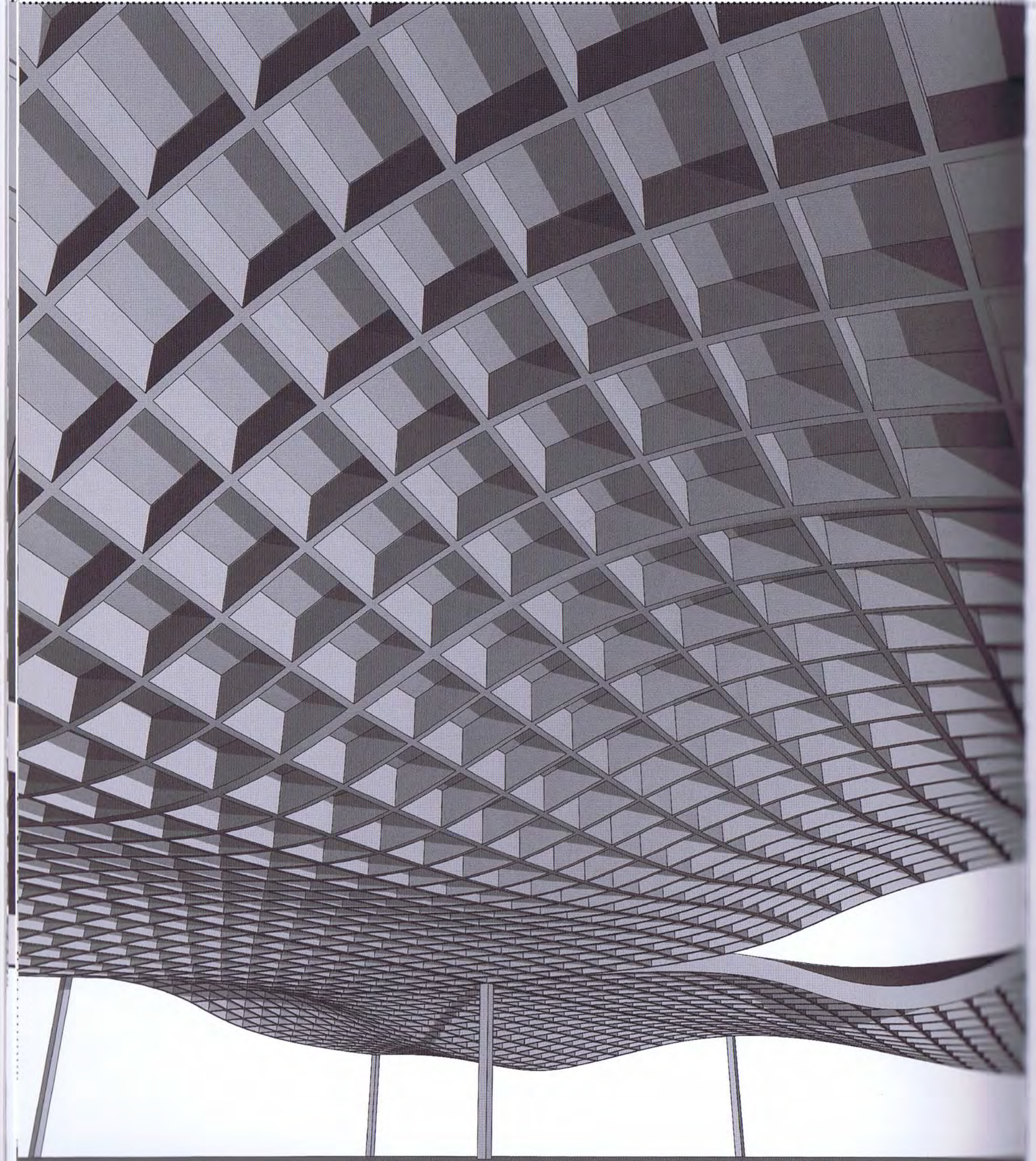
Horizontal / Two-Way Frame



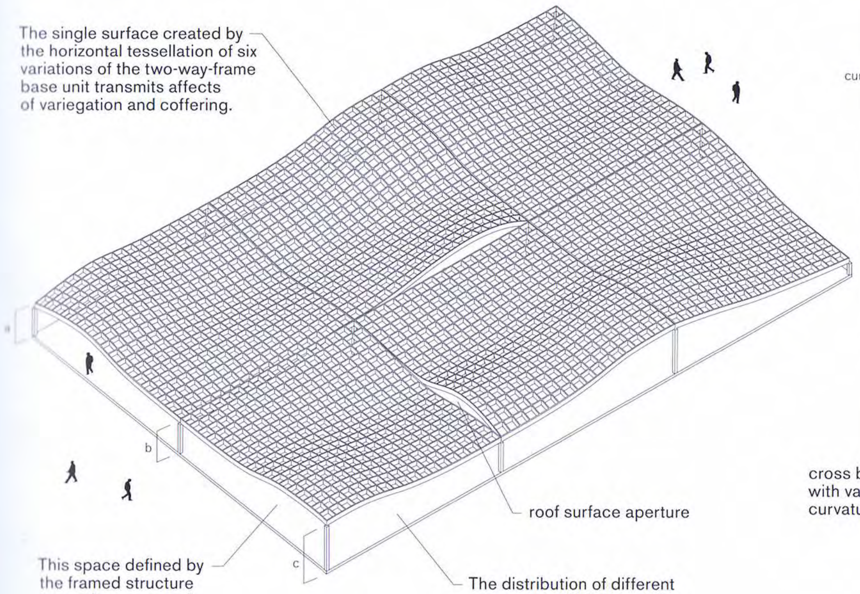


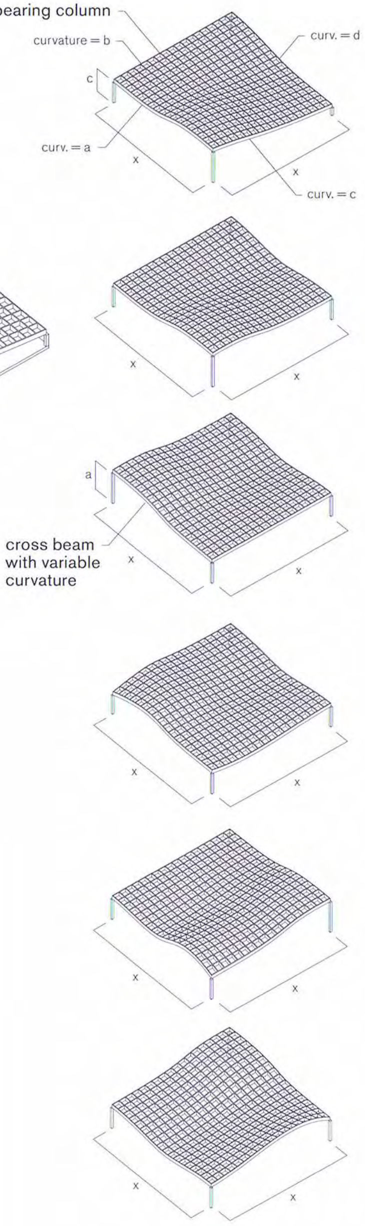
This horizontal form is produced by the horizontal tessellation of two two-way-frame base units that vary in their elevational profiles. Together they create a continuous roof surface which transmits an optical affect of undulation and coffering, and an acoustical affect of diffusion.

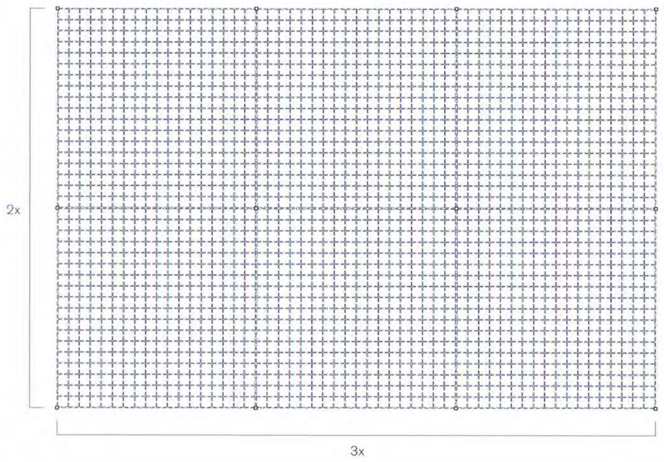
Variegation, Coffering, Diffusion



Horizontal / Two-Way Frame



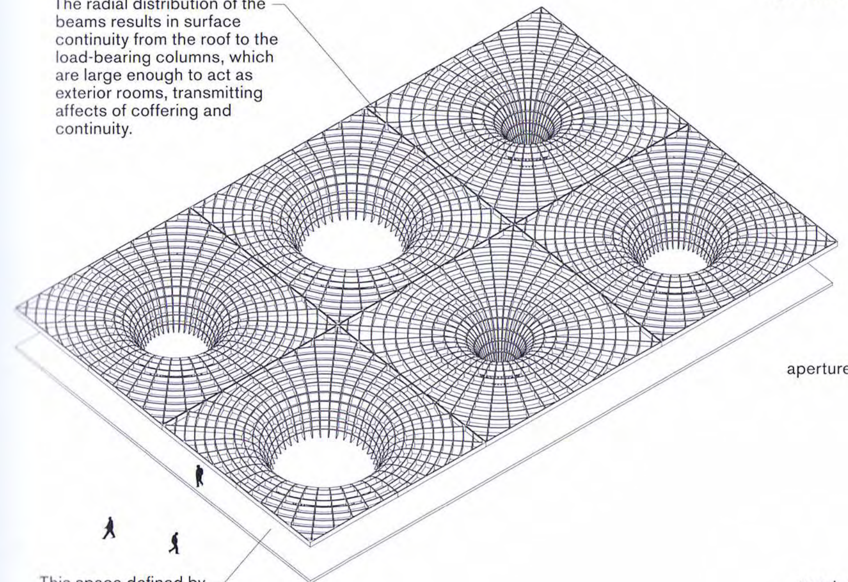


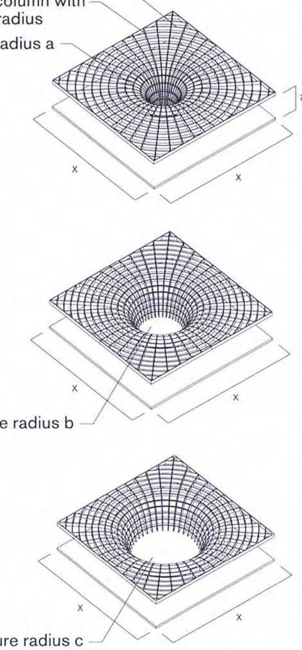


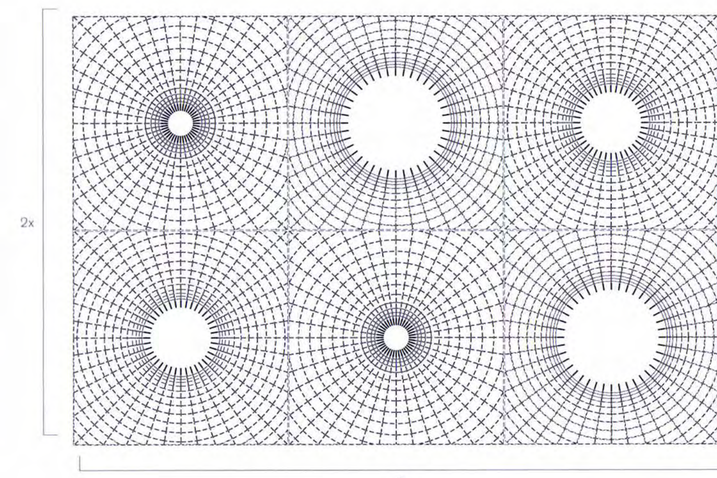
This horizontal form is produced by the horizontal tessellation of several base units composed of a regularly spaced grid of beams, the curvature of which varies irregularly as the base unit repeats, producing an increase or decrease in the curvature of the roof, and breaks between each of the curved parcels of which it is composed. These changes in height result in irregularly shaped apertures because of the differences in curvature from one parcel to the next of the surface. The undulating and discontinuous roof surface transmits an optical affect of variegation and coffering, and an acoustical affect of diffusion.

Continuity, Coffering, Diffusion

Horizontal / Two-Way Frame

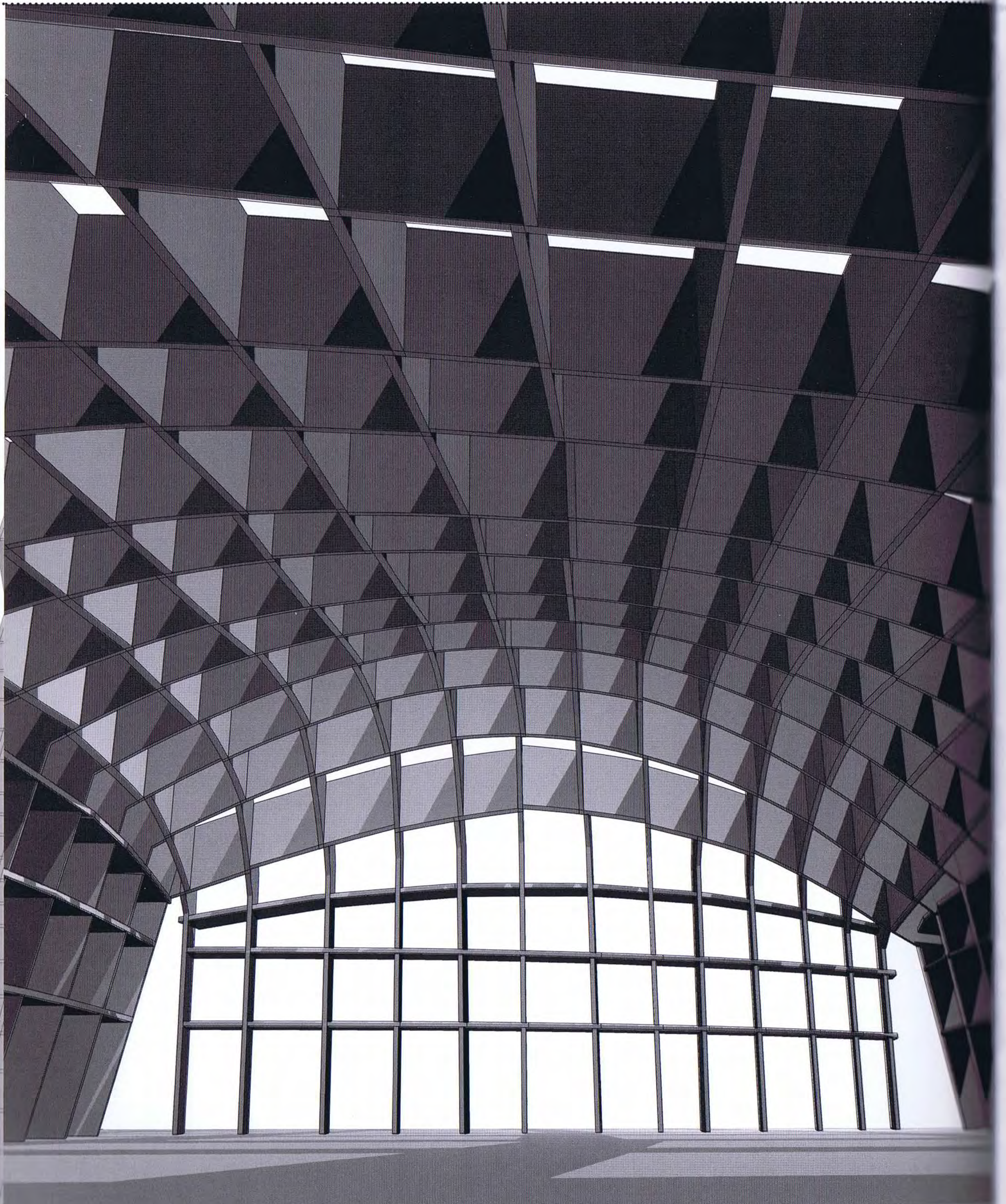






This horizontal form is produced by the tessellation of a base unit composed of a grid of two-way beams arranged in a radial pattern and bent to produce, simultaneously, the roof and its supporting walls. The radial bent frame produces circular void spaces that vary in scale as the base unit tessellates along the horizontal extension, introducing different degrees of porosity to the plan. This two-way frame transmits an optical affect of continuity and coffering, and an acoustical affect of diffusion.

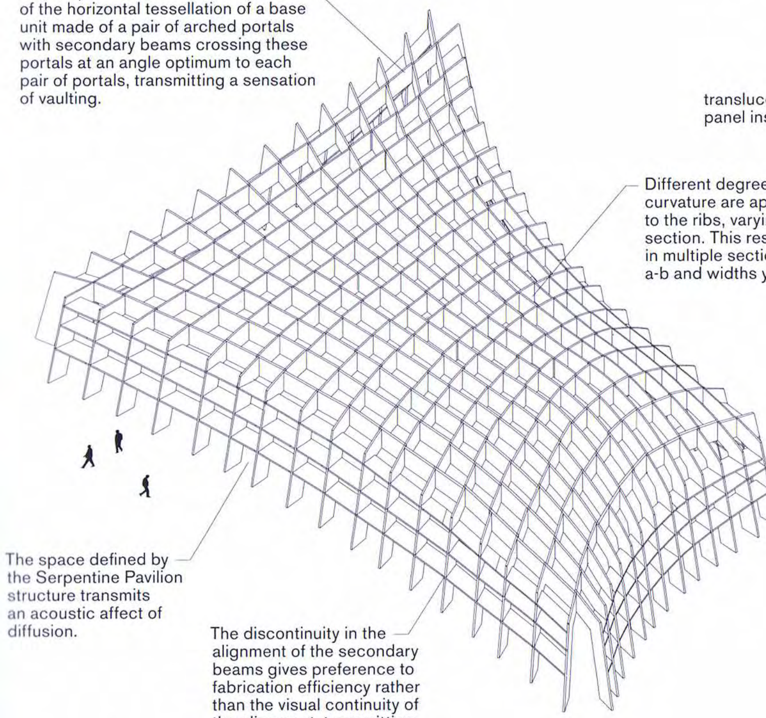
Coffering, Vaulting, Discontinuity, Orientedness, Diffusion



Horizontal / Two-Way Frame

SERPENTINE PAVILION | A. SIZA, E. SOUTO DE MOURA; C. BALMOND – ARUP | LONDON, UK | 2005

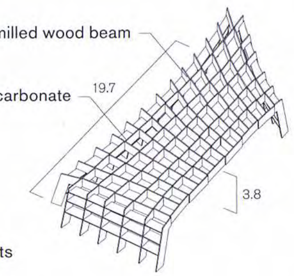
The Serpentine Pavilion is the result of the horizontal tessellation of a base unit made of a pair of arched portals with secondary beams crossing these portals at an angle optimum to each pair of portals, transmitting a sensation of vaulting.

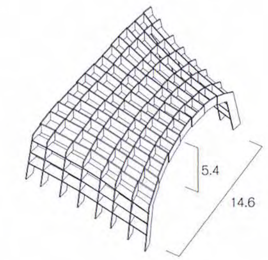


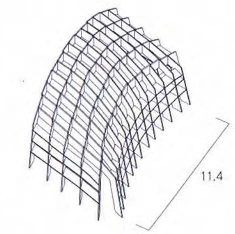
Different degrees of curvature are applied to the ribs, varying the section. This results in multiple section heights a-b and widths y-y'.

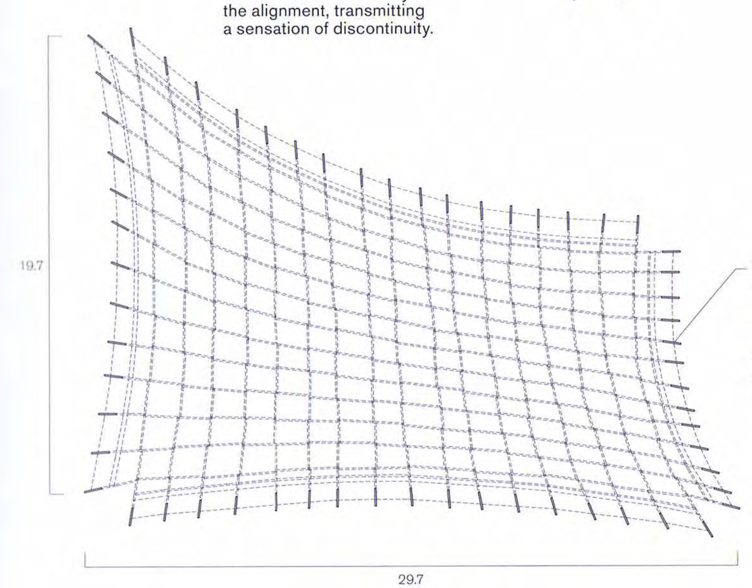
The space defined by the Serpentine Pavilion structure transmits an acoustic affect of diffusion.

The discontinuity in the alignment of the secondary beams gives preference to fabrication efficiency rather than the visual continuity of the alignment, transmitting a sensation of discontinuity.





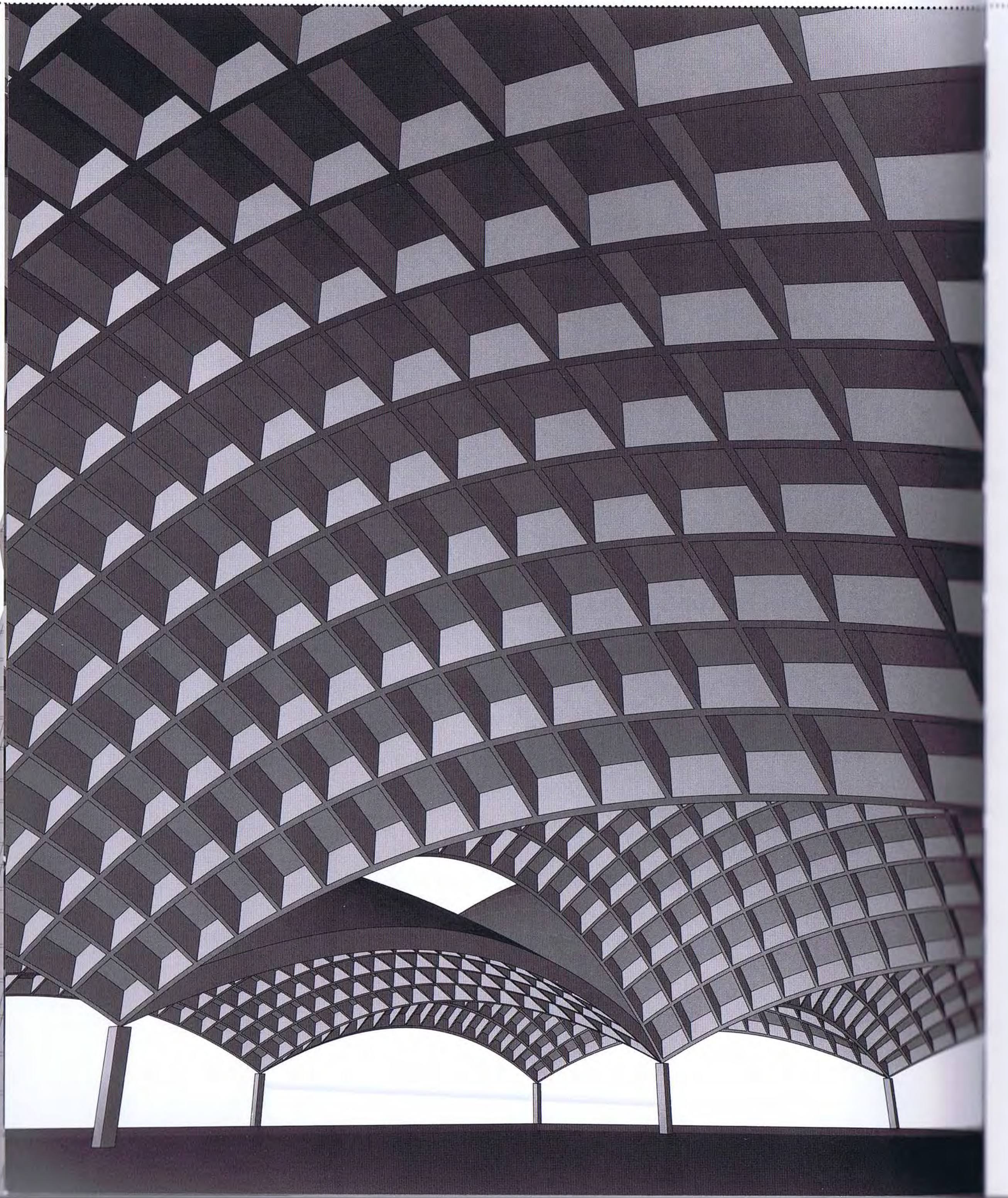




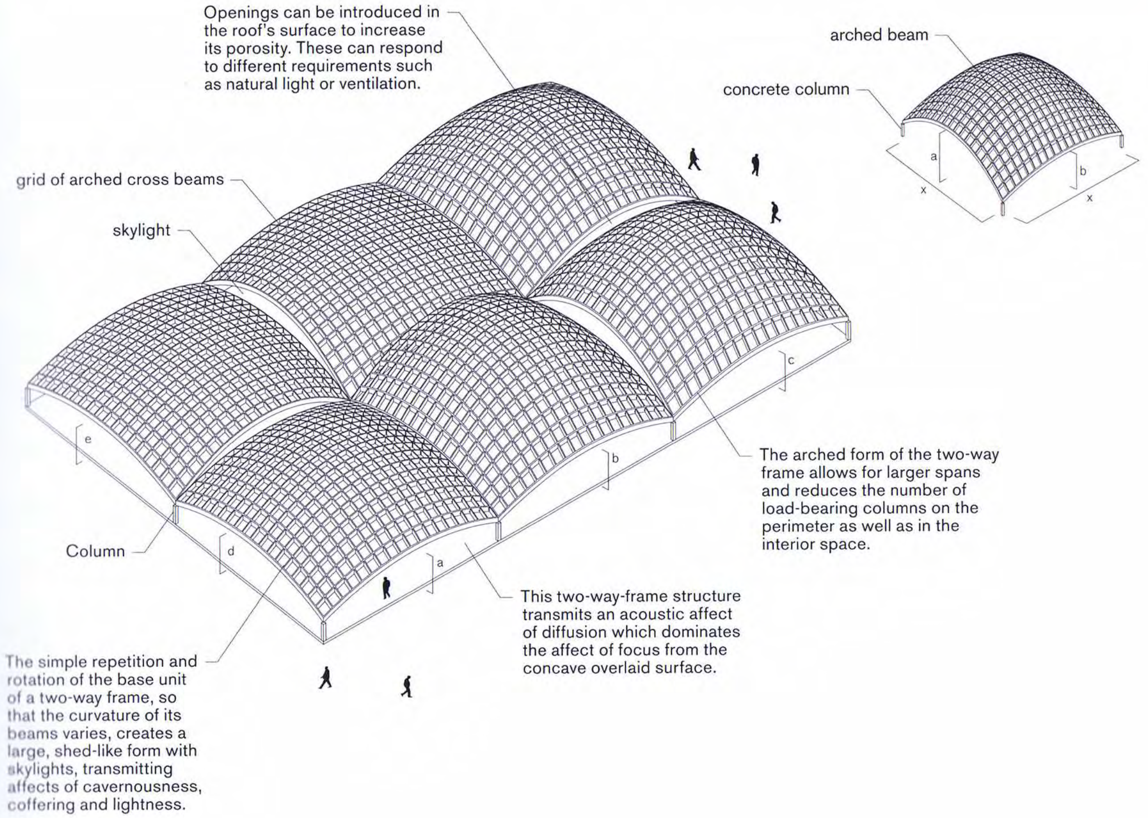
The curved profile in both plan and section of the portals, which vary in span as well as in their spacing, creates a form that is both concave in section and convex in plan form resulting in affects of vaulting and directionality.

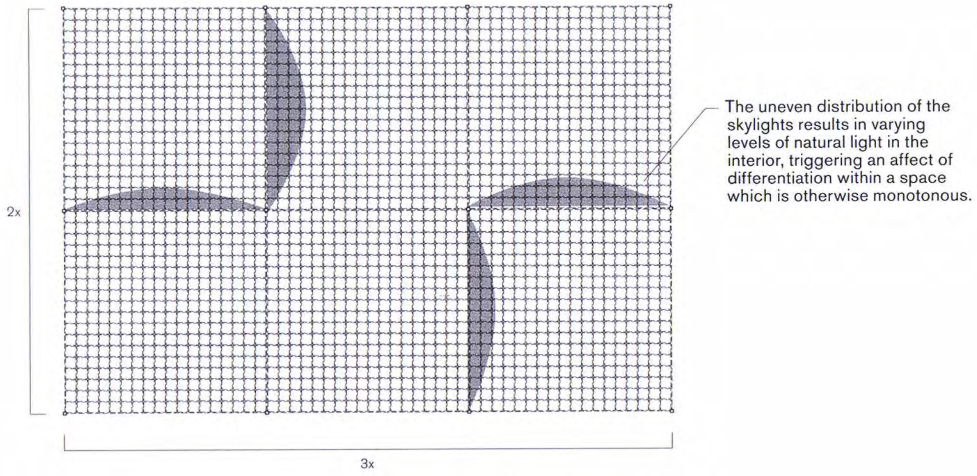
The Serpentine Pavilion is formed by the horizontal tessellation of interlocking rectangular beams, which together behave like a two-way frame. The beams vary in profile as they tessellate to introduce varying degrees of curvature to the form, modifying the volume and enclosing the interior as a vaulted space. In this type of frame the density of the interlocking beams as well as their scale can be varied to regulate the degree of porosity of the overall assemblage. The Serpentine Pavilion transmits an optical affect of coffering, discontinuity, orientedness and vaulting, and an acoustical affect of diffusion.

Cavernousness, Coffering, Lightness, Diffusion



Horizontal / Two-Way Frame



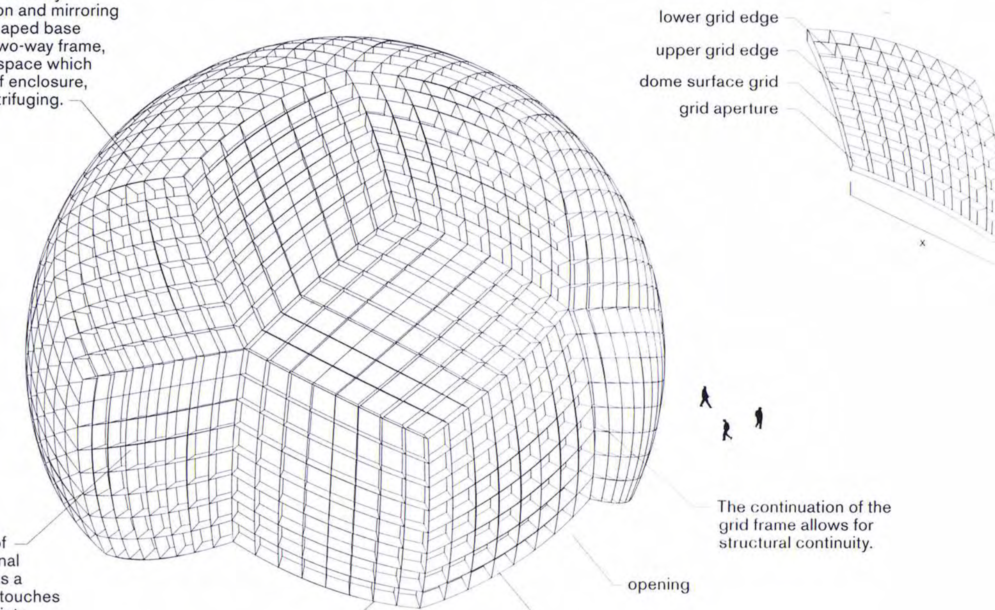


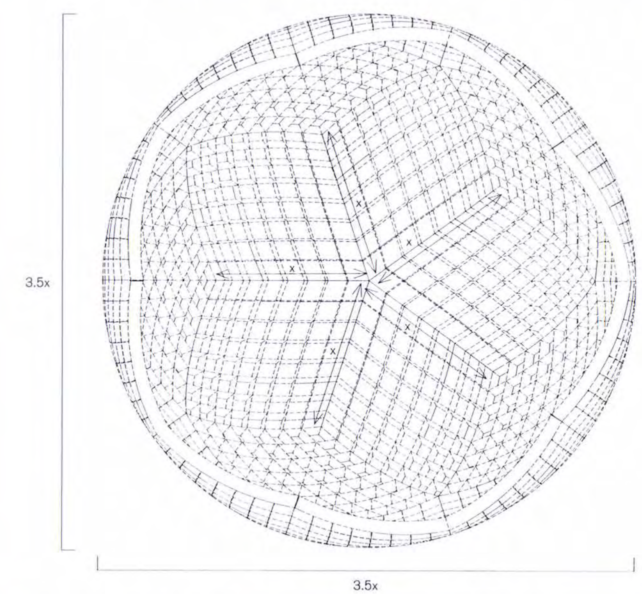
This horizontal form is produced by the horizontal tessellation of a regular grid of beams that varies in curvature as it spans in two directions, producing an increase or decrease in the height of the enclosed volume. This curved roof surface transmits an optical affect of cavernousness, lightness and coffering, and an acoustical affect of diffusion.

Enclosure, Repetition, Centrifuging, Centrality, Lightness, Diffusion

Curved / Two-Way Frame

EGG-CRATE GEODESIC STRUCTURE | R. BUCKMINSTER FULLER | NEW YORK CITY, USA | 1952



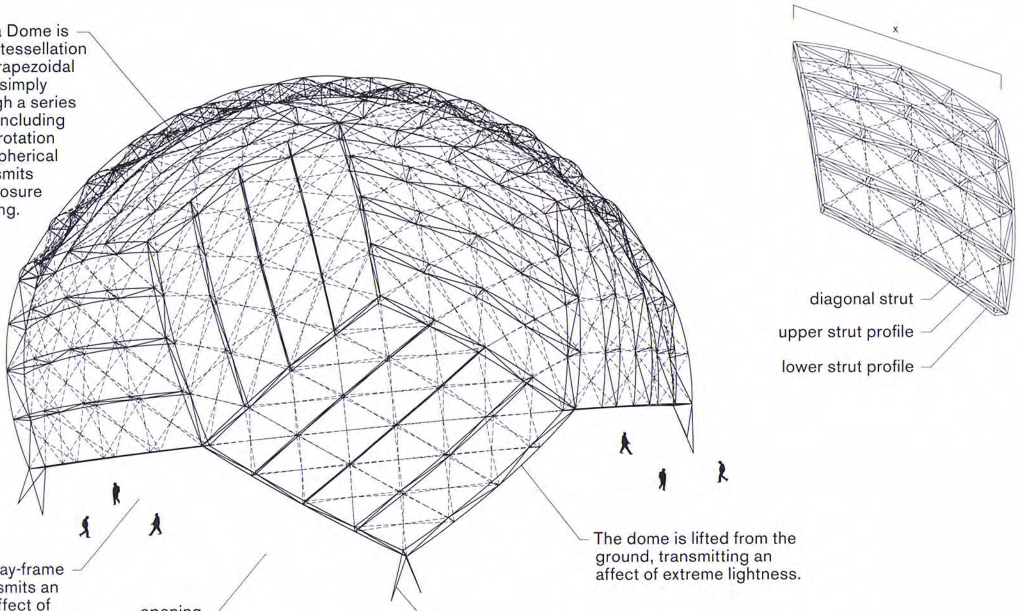


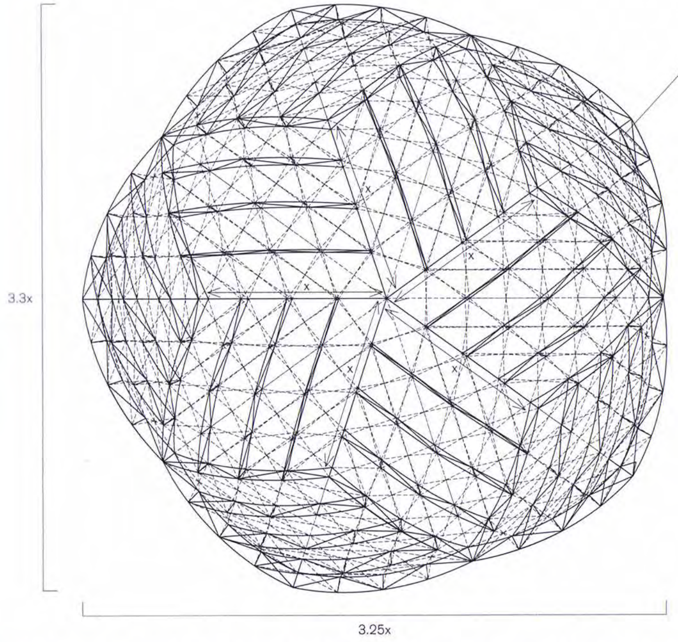
The Egg-Crate Geodesic structure is formed by the curved tessellation of a base unit composed of curved beams to create a regular grid. Radial tessellation of the base unit results in a form that approximates to a dome which is evenly perforated because of the regular character of the enclosing frame. The Dome transmits an optical affect of enclosure, repetition, centrifuging, centrality and lightness, and an acoustical affect of diffusion.

Enclosure, Centrifuging, Lacing, Lightness, Specularity, Focus

Curved / Two-Way Frame

DOME PROJECT, UNIVERSITY OF MINNESOTA, SCHOOL OF ARCHITECTURE | R. BUCKMINSTER FULLER | MINNEAPOLIS, USA | 1953





The Minnesota Dome is formed by the curved tessellation of a base unit composed of a double grid of curved struts, tubular in section, which are interconnected by a set of diagonal strings. A simple radial repetition of the base unit results in a form that approximates to a dome, but a more complex tessellation can occur if the depth of the base unit is varied to create, for example, a frame of variable density or an irregular perimeter. The Minnesota Dome transmits an optical affect of enclosure, centrifuging, lacing and lightness, and an acoustical affect of specularity and focus.