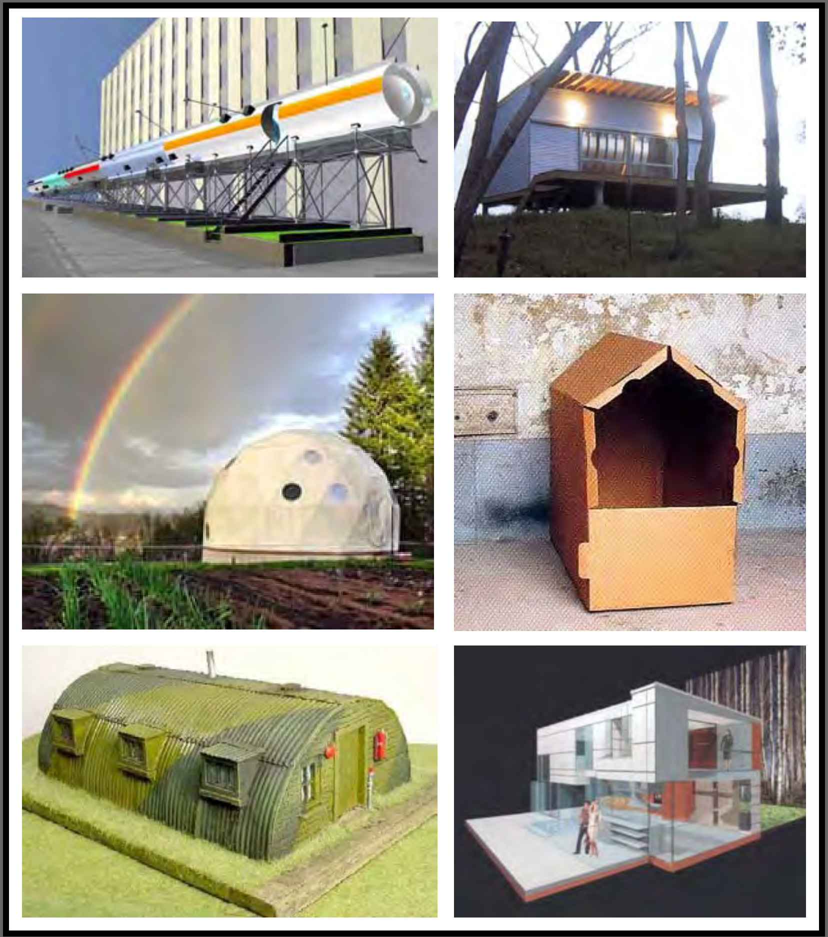
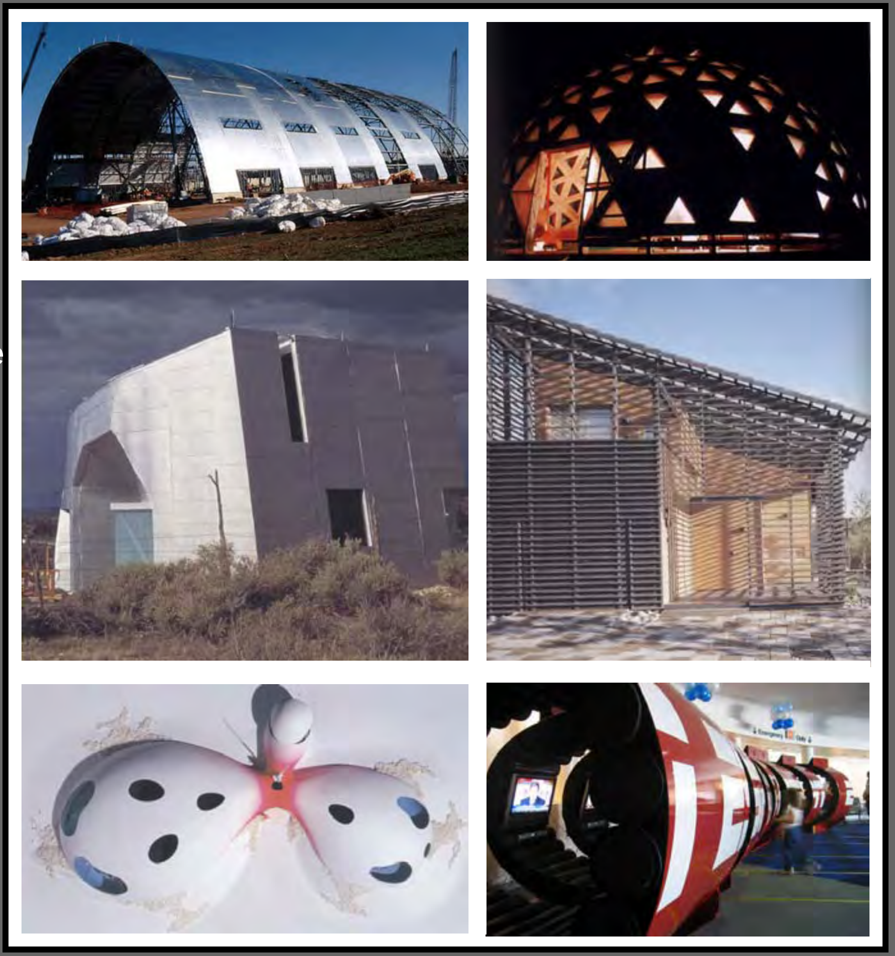
For chapters A, B, C of this report please go to the "Shelter Design and Construction. Part I".

Go to the list of contents



SECTION D : CONSTRUCTED FACILITIES



Constructed facilities primarily comprise hard, rigid prefabricated elements such as shells and frames with panels and/or metallic skins that are transported as “kit” parts and assembled at the site of use. They typically require more time and labor to implement than modules, but are often more compact for shipment and afford more design versatility.

- Shell-type structures include:
  - Domed systems
  - Arched systems
  - Cylindrical systems
- Panel-type structures include:
  - Geodesic frame systems
  - Arched frame systems
  - Box frame systems
  - Rigid wall systems

CONSTRUCTED FACILITIES

SHELL & PANEL/ SKIN SYSTEMS

Ulrich Muther

FEATHERWEIGHTS

Baywatch on the Baltic was a ferro-cement shell structure on a base used as a lifeguard station overlooking sand dunes.

- The thin shell shelter was developed by East German engineer Ulrich Muther who came from a family of architects and ship captains and applied shipbuilding approaches:
  - Muther's buildings ranged in types, including enclosures for competitive cycle training, roofing for swimming pools and planetariums that were exported to Finland, Kuwait, Libya and the nearby Federal Republic of Germany.

Baywatch on the Baltic

Domed Systems

Ulrich Muther

FEATHERWEIGHTS

17.8m Diameter Spacemaster Planetarium in Libya with Flanking Shells

Domed Systems

CONSTRUCTED FACILITIES

SHELL STRUCTURES

Jan Kaplicky proposed this house design in 1997, which is envisioned for a rural or semi-rural setting where the interior would be cut into the land to create an unobtrusive low profile appearance.

- The home would be a semi-monocoque aluminum structure with retaining walls:
  - Glazed openings in the shell would provide natural illumination and views of the outside landscape.
  - Open interior plan living and sleeping areas would be defined by an undulating sculpted floor rather than by partitions.
  - Bathrooms and certain other elements would be delivered to the site as prefabricated pods.

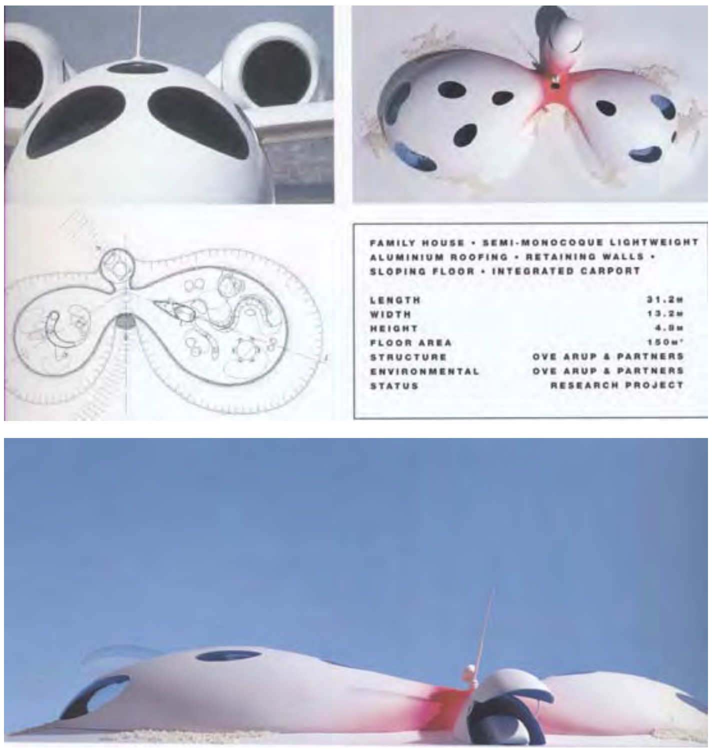
Jan Kaplicky **FUTURE SYSTEMS**

Semi-Monocoque House Design

Domed Systems

Jan Kaplicky

FUTURE SYSTEMS



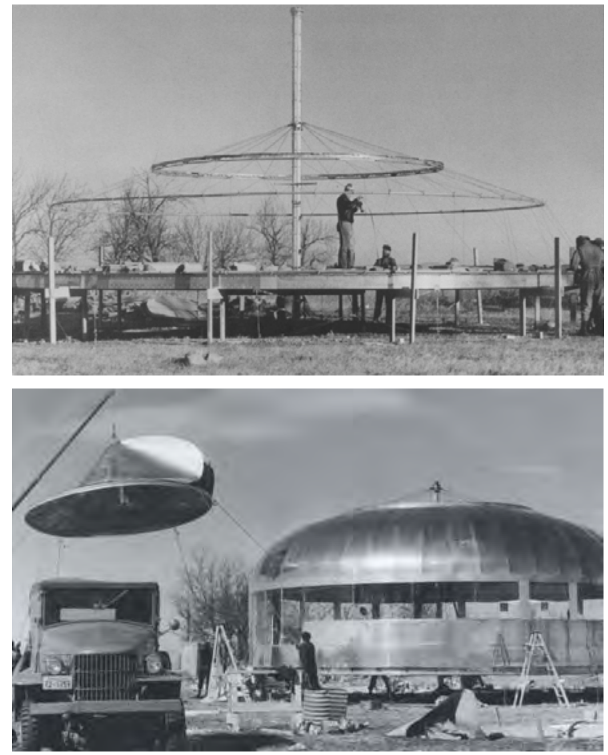
Semi-Monocoque House Design

Domed Systems

CONSTRUCTED FACILITIES

SHELL STRUCTURES

Buckminster Fuller FEATHERWEIGHTS



Witchita House

Bucky Fuller's Wichita (Kansas) House was based up principles he developed for an earlier Dymaxion model and applied them for a broader market in 1944.

- The UFO-like circular structure was made of aluminum sections arranged around a central mast with a ring lattice and attachment collar for suspending floors:

  -The Beech aircraft company that was familiar with lightweight aluminum construction including a roof dome cooperated in the design.

  -A prototype was assembled by 16 people in two days.

  -About 37,000 orders were received for the house, and mass production was planned for 250,000/year, but this never happened

Domed Systems

Jan Kaplicky and David Nixon collaborated in a series of studies that investigated lightweight building concepts that can be applied for industrial uses.

- This proposal uses standard prefabricated parts to minimize assembly time and labor:
  - The floor substitutes an interlocking deck normally used for emergency aircraft runways in lieu of conventional slab and foundation construction.
  - The enclosure is built from standard steel sandwich panels with integral stiffening and insulation that are formed into a three-point arch.
  - The arched enclosure is held down by anchor screws, with additional rigidity introduced by outrigger tension cables.
  - Support accommodations including offices, cloakrooms, heating and ventilating equipment would be contained in external mobile shelters.
  - A windmill generator could provide supplementary power.

Jan Kaplicky & David Nixon

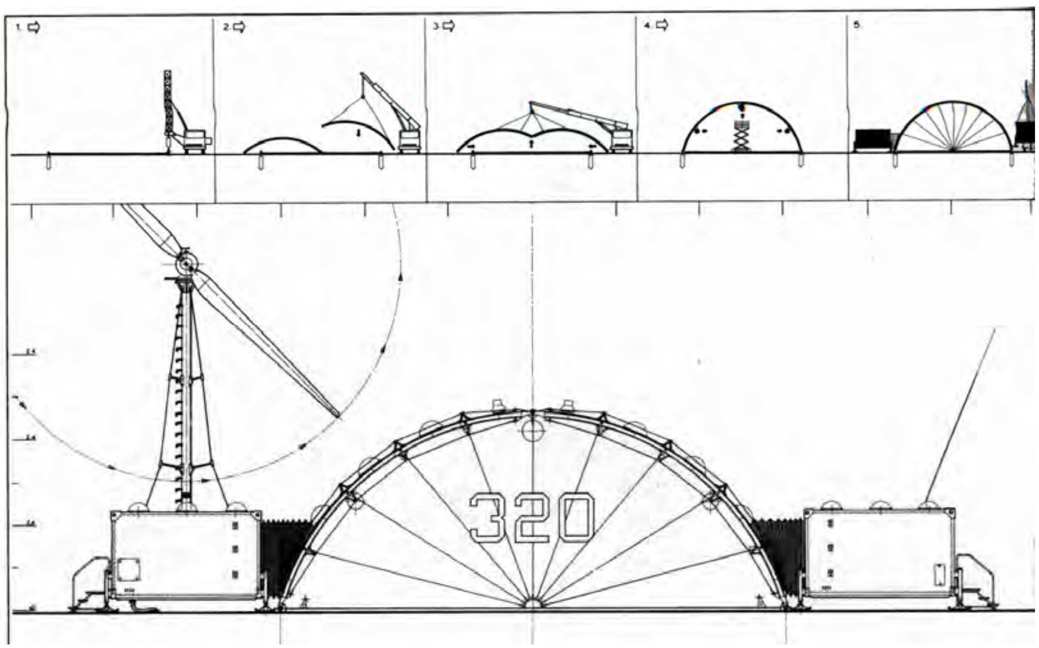
FUTURE SYSTEMS

Industrial Building Concept

Arched Systems

Jan Kaplicky &
David Nixon

FUTURE SYSTEMS



Industrial Building Concept

Arched Systems

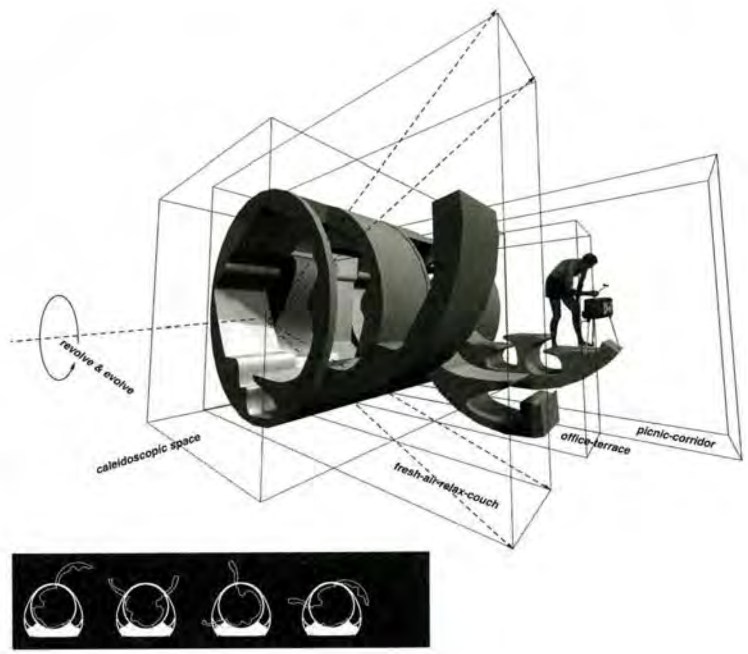
CONSTRUCTED FACILITIES

SHELL STRUCTURES

This housing system proposed in 2000 envisions connected cylinder sections of varying lengths that have been hinged drop-down walls that deploy following delivery to the site:

- The section segments can be custom-designed to provide facilities for sleeping, cooking and living/entertainment:
  - Sections could be coupled together in different combinations and numbers according to needs and desires of residents.
  - The drop-down walls would expose interior areas to outdoor surroundings, and would be closed during inclement weather conditions.

Alles Wirdgut **Living in Motion**



TurnOn – urban.sushi

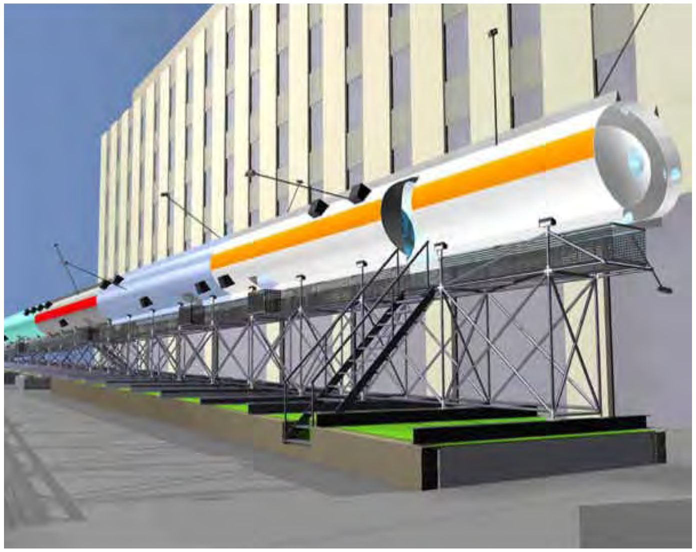
Cylindrical Systems

LOT-EK developed a "Vision Tube" for the 2000 Whitney Biennial at Rockefeller Center, New York comprised of 6 aluminum gasoline tanks joined into a continuous 210ft long space.

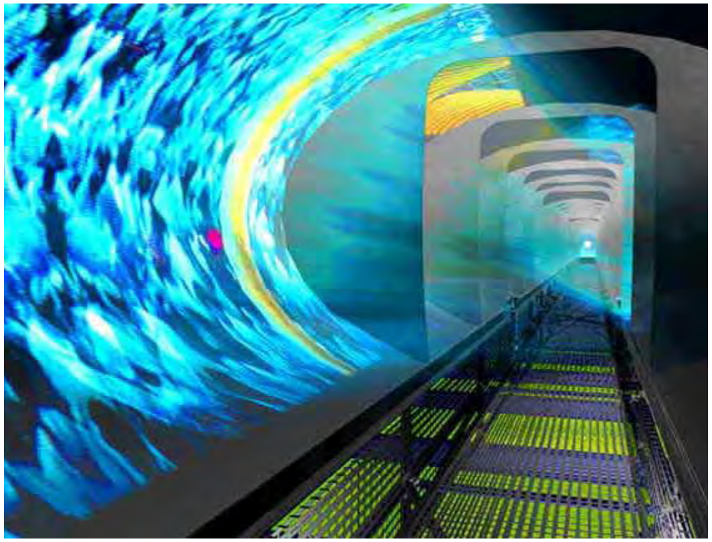
- Surveillance cameras on steel appendages survey outside life and zoom in on surrounding streets, gardens and the ice rink, offering views from the Tube's many eyes:

- Individual tanks are divided by baffle walls into which doorways are cut.
- Tank bottoms are also cut out, so that visitors walk on a lower catwalk with their upper bodies inside the tube.

LOT-EK ARCHITECTURAL STUDIO



Tanks are Supported by a Steel Scaffold



Gasoline Vision Tank Tube

Cylindrical Systems

LOT-EK proposed to create a student pavilion at the University of Washington, Seattle constructed using an 80ft long Boeing 747 fuselage section placed on a sloping site overlooking Lake Washington.

- The fuselage would be supported midair on a steel pipe cradle with a ramp to provide interior access:
  - The interior would be stripped down to reveal an intricate aluminum ribcage, and flooring on the main deck would be replaced with metal grating filled with clear resin.
  - A rotating floor/seating system made of “seating wheels” would take advantage of cargo space beneath the floor, enabling the interior to be set up in multiple configurations for different events:
    * Benches for lectures/classes
    * Lounge chairs for screenings
    * Flat floor for performances/parties
  - Perimeter projection screens could be pulled down to create a theater.

LOT-EK ARCHITECTURAL STUDIO

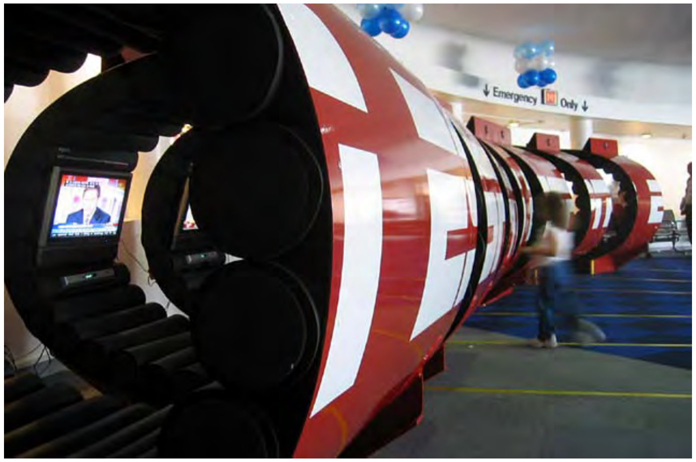
Aircraft Fuselage Student Pavilion

LOT-EK ARCHITECTURAL STUDIO

LOT-EK transformed a petroleum trailer tank into a set of sections for lounging and TV viewing at the Jet Blue terminal at the New York JFK Airport.

- The 35ft long tank was sliced into 8 rings:
  - Each module is lined all around with rubber tubing and equipped with 26-inch flat screen TVs showing ESPN in high definition.
  - Viewers lounge in the privacy of single or double sections that can serve as viewing capsules.

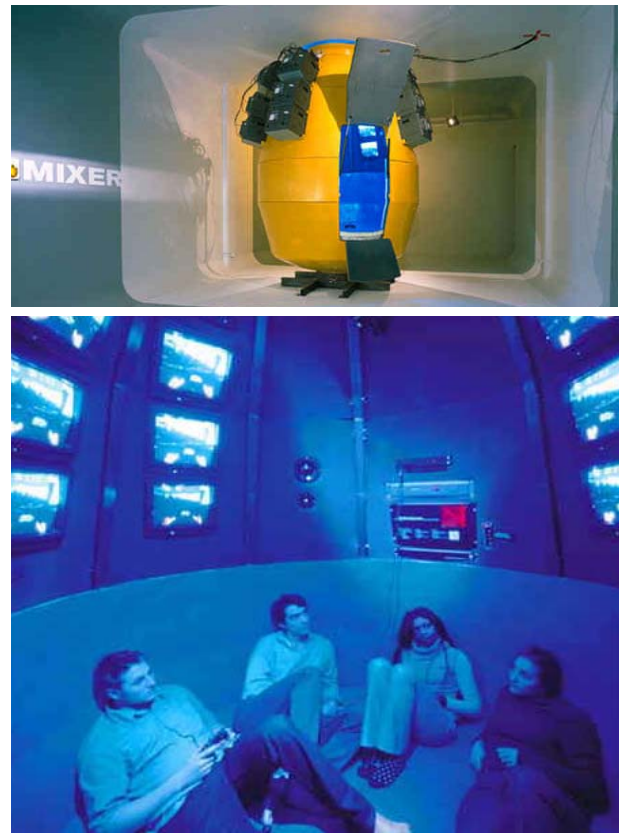
TV Viewers Lounge in Privacy



Petroleum Tank Lounging Tube

Cylindrical Systems

LOT-EK ARCHITECTURAL STUDIO



Cement Mixer Media Cocoon

LOT-EK transformed a steel cement mixer into a modern media-viewing module at the Henry Urbach Architecture Gallery.

- The "Cocoon" is designed for lounging, viewing and contemplative "dreaming":
  - The space offers a plush, intimate environment that is animated by multiple forms of entertainment and information.
  - Fitted with 12-inch monitors connected to a variety of audio/video inputs, the unit affords surveillance cameras, satellite TV, a DVD player, and Playstation 2.
  - The mixer pivots on its central axis to change the spatial orientation and create a dynamic experience.

Buckminster Fuller ("Bucky") is credited with many innovations. Most notable of these is the geodesic dome. These structures have found a wide variety of applications around the world, including private dwellings, weather stations, emergency shelters, mobile military housing and large event pavilions.

Buckminster Fuller

The Geodesic Dome

Geodesic Frame Systems

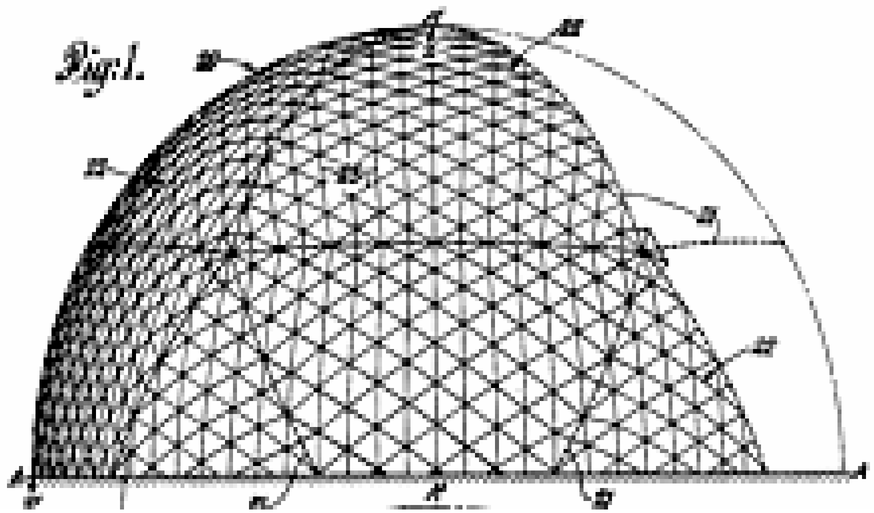
Buckminster Fuller's Dome House located in Carbondale, Illinois is one of the 240 structures created by him between 1922-27.

The Home Dome

Geodesic Frame Systems

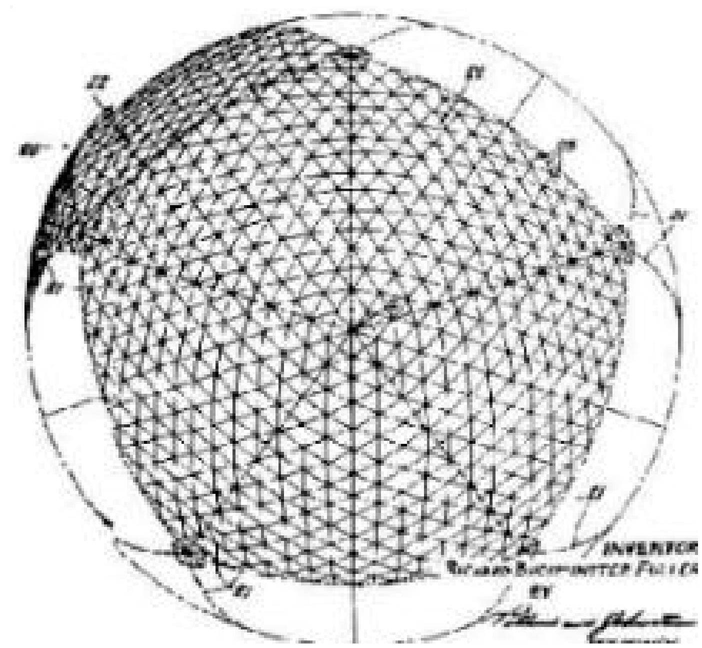
The shape of a geodesic dome is established by a pattern of triangles forming an interlocking web of "geodesics" (the shortest path between two points in two-dimensional geometry).

- As stated in his 1954 patent, this shape is self-reinforcing, requiring less material than any other form:
  - While conventional buildings may weigh about 20lbs/sq.ft. of floor space, a geodesic dome can weigh less than 1lb/sq.ft.
  - This can not only enable buildings to be built less expensively, but also with less labor and stronger (greater resistance to earthquakes and wind loads).

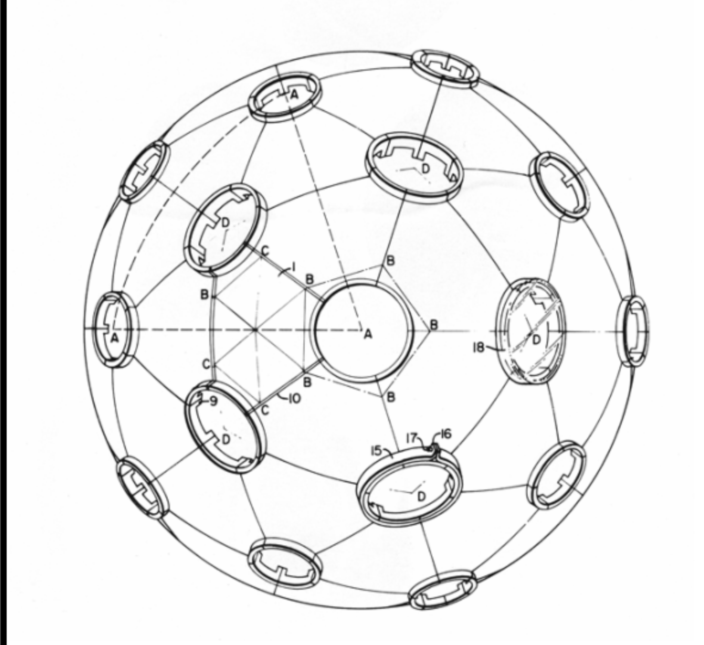


Geodesic Dome Patent

Geodesic Frame Systems

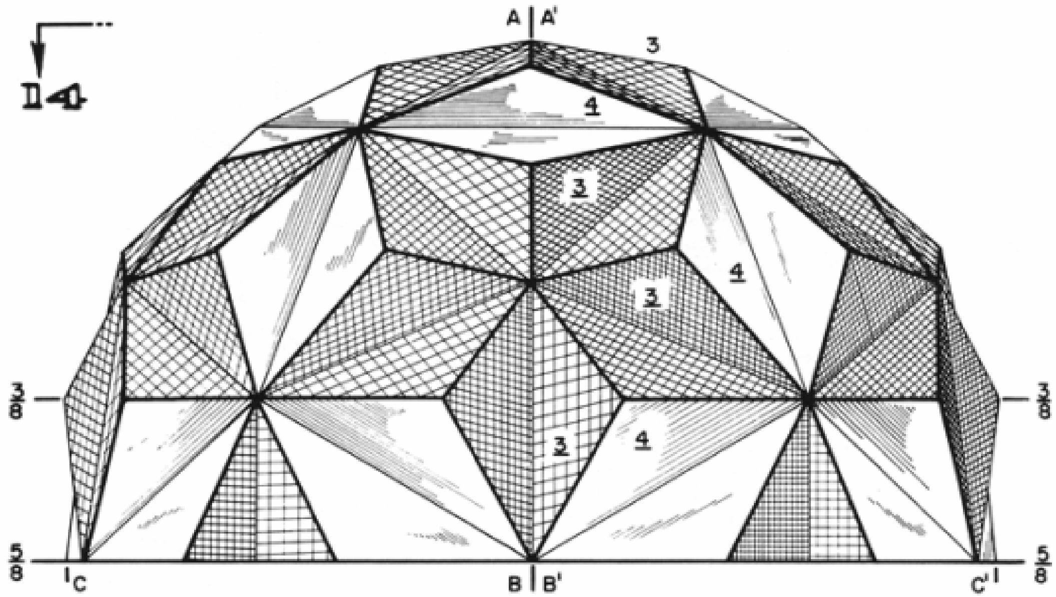


Geodesic Dome Patent



Geodesic Dome Patent

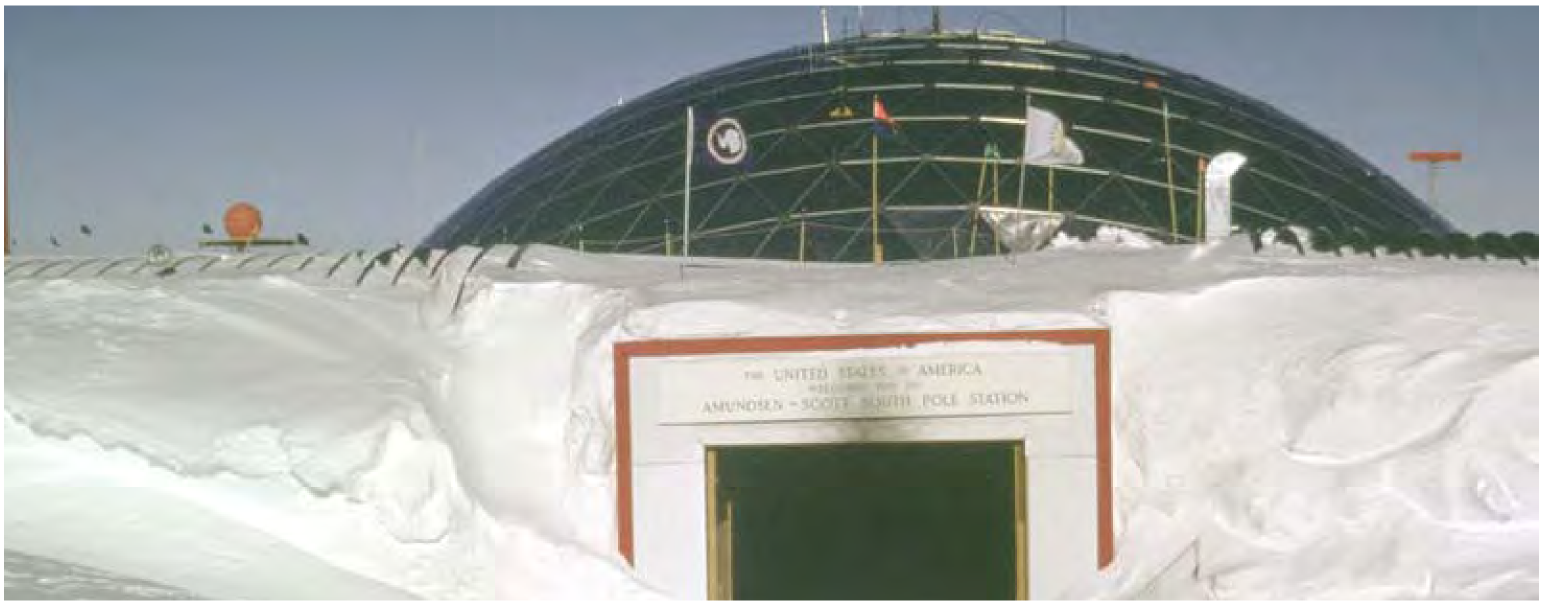
Geodesic Frame Systems



A sphere encloses more volume with less surface area than any other form. Thus, any portion of a sphere (such as a geodesic dome) has the least amount of surface to lose heat or to catch and be vulnerable to damaging winds.

Laminar Dome Patent

Geodesic Frame Systems



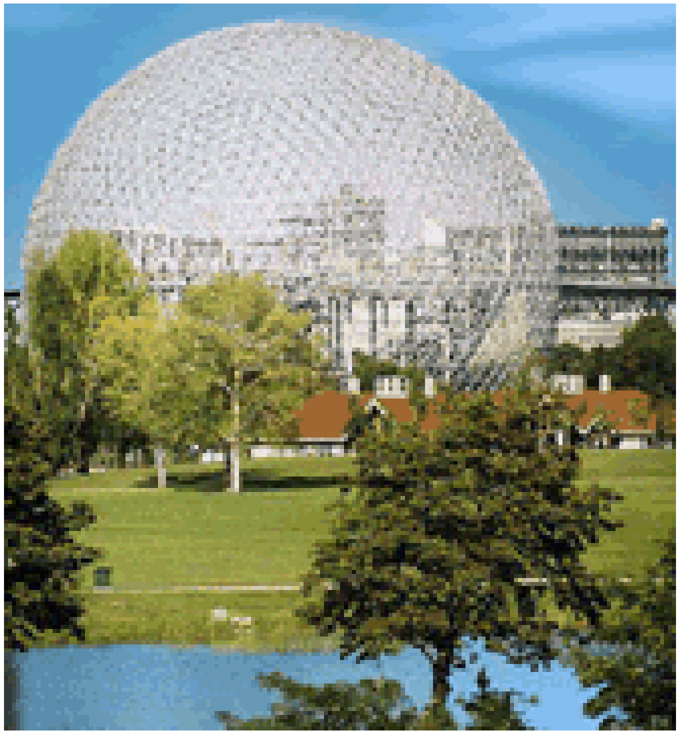
Large Geodesic Dome Over the South Pole

Geodesic Frame Systems

CONSTRUCTED FACILITIES

SHELL STRUCTURES

20 Storey- High Pavilion



The US Pavilion at Expo ‘67, Montreal

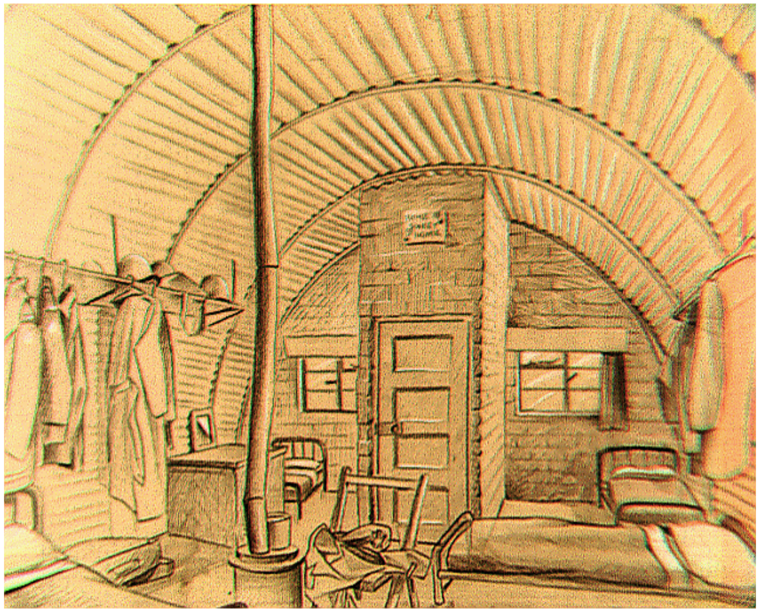
Geodesic Frame Systems

MS-SPACE ARCHITECTURE SICSA

PORTABLE ARCHITECTURE

Designed by Bjorn Farlein Nissen (England) in 1916, this structure became the standard U.S. building overseas, and later found broad civilian use as barns, henhouses and temporary housing (under the name Nissen-Petren Houses). The design had a semi-circular cross section, cavity walls, and required no special skill to erect:

- It used common materials such as concrete, corrugated steel, and plasterboard.
- Construction typically involved the following steps:
  - Wooden bearers were laid on level ground, usually on brick supports.
  - Steel bows or ribs were bolted to the bearers and wood purlins were attached using hook bolts.
  - Wood floor joists were screwed to the bearers to receive timber floor panels.
  - End panels were attached and internal linings were added.
  - Exterior corrugated skin was attached.



The Nissen Hut

Arched Frame Systems

MS-SPACE ARCHITECTURE SICSA

PORTABLE ARCHITECTURE

Weather Proofing a Nissen Hut

The Nissen Hut

Arched Frame Systems

PORTABLE ARCHITECTURE

The Quonset Hut (named from the first site of manufacture at Quonset Point, North Kingston, Rhode Island) was based upon the Nissen Hut developed by the British during World War I.

- Principal improvements over the former Nissen type were an interior pressed wood lining, insulation, and a tongue-and-groove wood floor:
  - The original design was a 16ft x 36ft structure framed with steel members with an 8ft radius.
  - The most common design created a standard size of 20ft x 48ft with a 10ft radius (720ft^2).
  - The open interior space was versatile, enabling uses for barracks, offices, medical/dental facilities, isolation wards, latrines and other applications.

Quonset Huts

Arched Frame Systems

To reduce shipping volume and weight, a redesign incorporated lighter corrugated galvanized sheets for covering and substituted ½ inch plywood floors for earlier one-inch tongue-and-groove:

- The new design was larger (20ft x 48ft) and lighter (3.5 tons instead of 4.0 tons).
- In 1943, 4ft overhangs were added at ends to prevent driving rains and sunlight from entering bulkheads (extending the length from 48ft to 56ft).
- As finally developed, the Quonset Hut required less shipping space then did tents, and accommodated an equal number of personnel.
- Larger warehouse applications were developed for Navy advance-base use (40ft x 100ft structures weighing 12.5 tons with shipping volume of 350ft³).

WIKIPEDIA

Quonset Huts

Arched Frame Systems

M. Pod is a dome-shaped dwelling with an ornate timber screen and bronze mesh to keep insects out of interior areas.

- A hemispherical roof made of ceramic tiles clips in place over a framework of rolled steel beams.
- The 12 meter diameter building provides a single bedroom unit with an en-suite bathroom, living room, dining room and kitchen.
  - Several pods can be linked together to enlarge the space or create a cluster of dwellings.

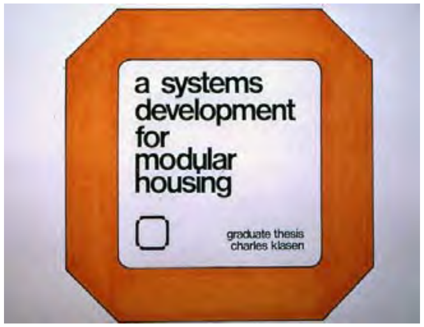
Steven Blaess

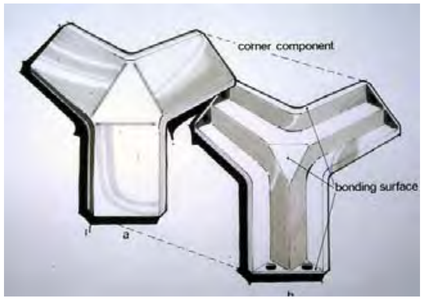
MOVE HOUSE

The M-Pod

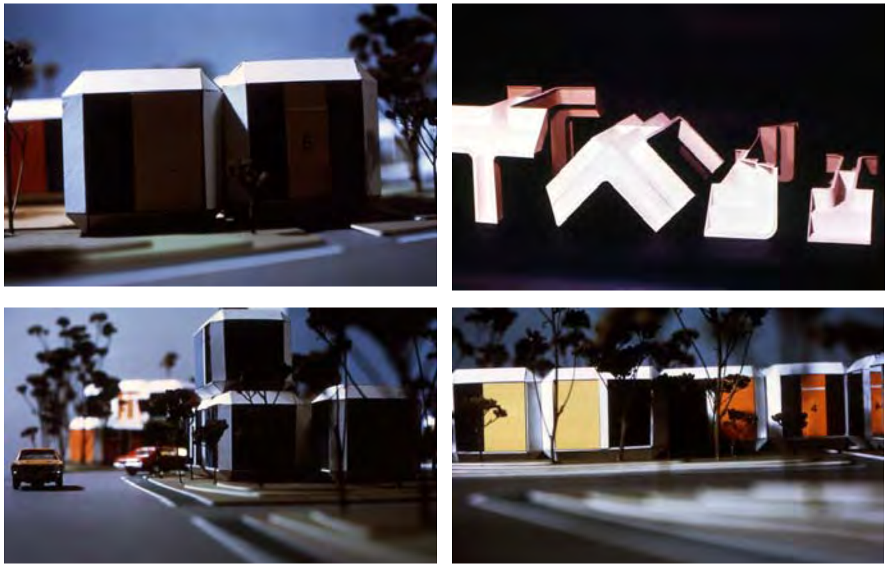
Arched Frame Systems

Charles Klasen designed a molded 2- part frame system using three different shaped elements which can generate single, multiple and stacked housing units. Custom wall, floor and roof panels would be attached with a variety of window/ door and color/ finish options.





Charles Klasen **University of Illinois, Industrial Design**



Modular Frame Concept

Box Frame Systems

Nottoscale

PREFAB MODERN

The Modulome System is based upon automobile industry design approaches.

- The core of the system is a 16ft x 48ft x 10ft structural steel chassis:
  - The chassis is trucked to the site completely assembled where it is placed upon columns that have been emplaced in advance.
  - The frame has predrilled holes to enable element panels to be bolted in place, including exterior walls, roof and flooring.
  - Other building units such as kitchen and bathrooms can be placed anywhere within the frame.
  - The panels and functional units can be detached to enlarge or change the dwellings as desired over time.

The Modulome System

Box Frame Systems

Anderson Anderson Architecture

PREFAB MODERN

The Kennedy House

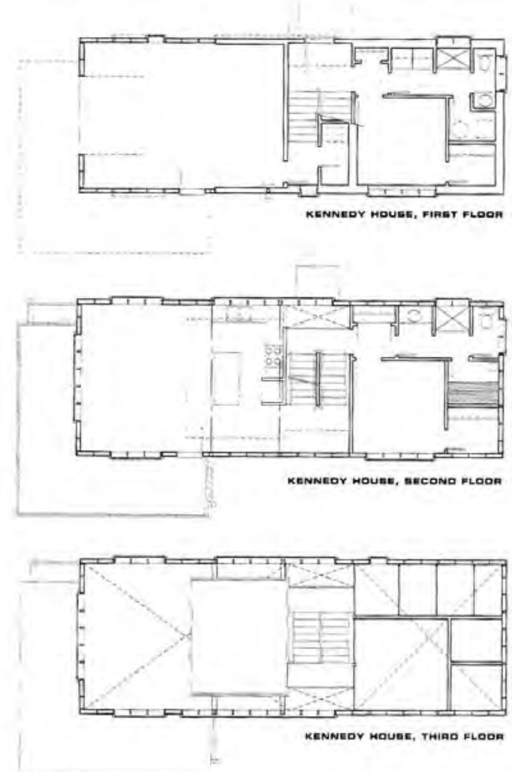
The Kennedy House used prefabricated panels that were assembled about 10 miles from the site.

- Construction applied a “mass-customization” system approach using panels that can be made in different lengths depending on each building’s needs:
  - “Balloon frame” construction provides an arching roof.
  - The house frame was delivered to the site and was assembled in eight hours.
  - Panels that form the exterior are made of insulated Styrofoam encased in plywood.
  - Windows can be maneuvered around and placed where desired after the panels are installed.

Box Frame Systems

Anderson
Anderson
Architecture

PREFAB MODERN



The Kennedy House

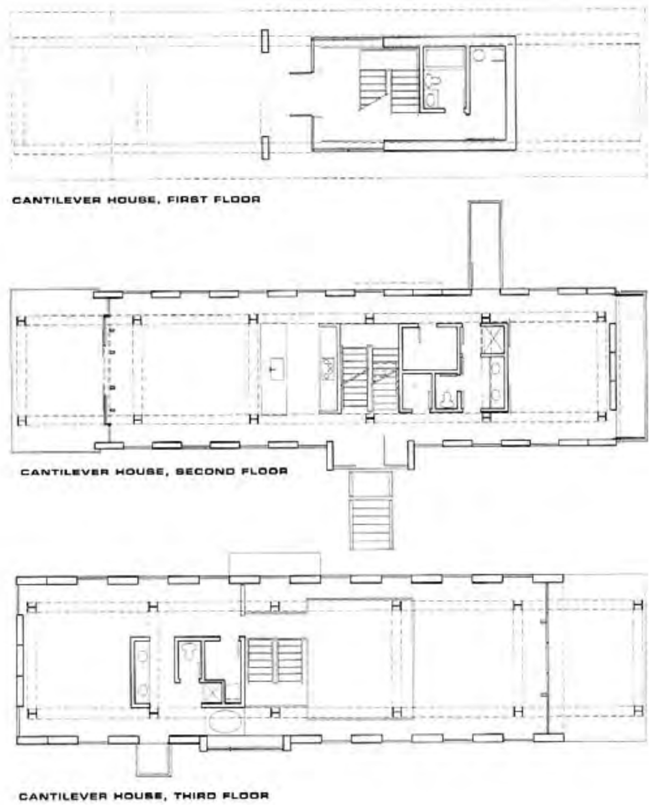
Box Frame Systems

Anderson Anderson Architecture

PREFAB MODERN

Cantilever House prototypes have been built in Granite Falls, Washington and San Diego, California using Styrofoam and plywood or plasterboard panels attached to a prefabricated steel frame for the entire structure (floors, walls and roof).

- The cantilever design enables the ground floor and foundations to be very small, reducing site preparation and foundation work.



The Cantilever House

Box Frame Systems

The Turbulance House exterior is constructed of 31 panels made of galvanized aluminum with flexible ribs spaced 14 inches apart to fit into a 40ft shipping container.

- The panels range in size from 6ft x10ft to 8ft x 22ft, with the largest weighing more than a ton:
  - Each panel is designed and fabricated using computer-generated templates.
  - Of the $300,000 budget, $175,000 went to the exterior.
  - Photovoltaic roof panels provide electricity, and a cistern on the side of the house collects water from the roof for site irrigation.
  - The floor contains a radiant heating system.

Steven Holl **PREFAB MODERN**

The Turbulence House

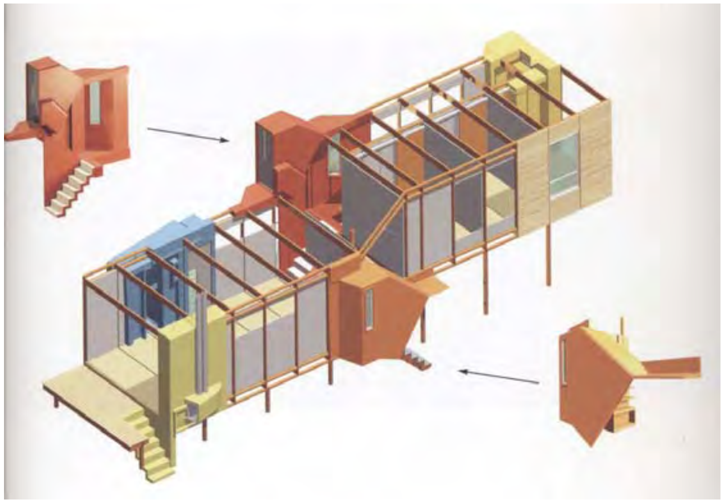
Box Frame Systems

The Composite Housing Project concept begins with a frame skeleton constructed by a contractor from wood or steel with attached add-on panels and module units.

- Combined indoor and outdoor elements in the add-on units include such components as an entrance door integrated with a staircase, another door integrated with a cabinet and storage room on the inside, and an exterior shower:
  - The outside surface of add-ons is made of epoxy with a variety of colors.
  - Add-ons would be sold by catalog, offering customers choices of color, type and size.
- An alternative "+ System" doesn't include add-ons, but places functional elements into 9ft x 3ft x 8ft shelf structures to achieve similar results.
  - The living area is located between shelving units on either side.

SUII Architecture + Design

PREFAB MODERN

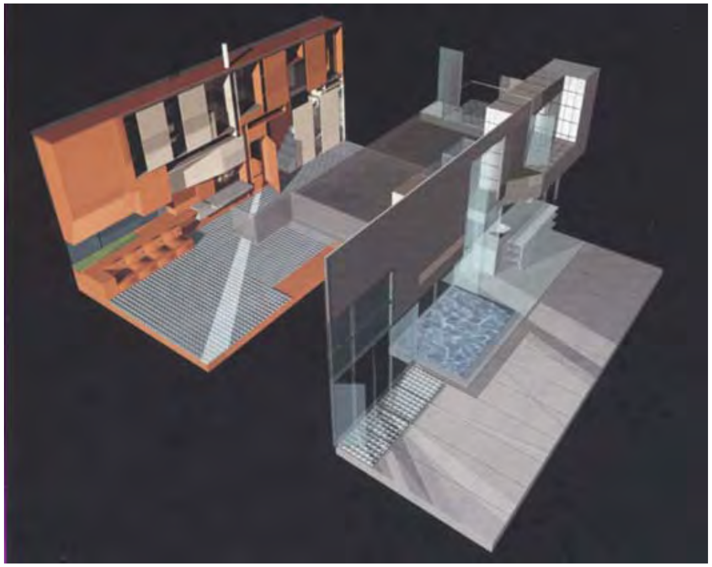


Composite Housing Project System

Box Frame Systems

SUII Architecture+ Design

PREFAB MODERN

The SUII + System Incorporates Functional Systems into “Shelving Units”

Box Frame Systems

CONSTRUCTED FACILITIES

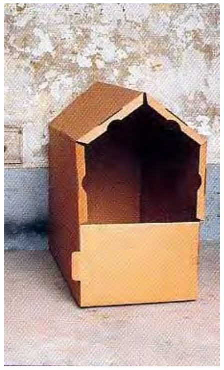
PANEL STRUCTURES

Oskar Leo Kaufmann

MOVE HOUSE

Architect Leo Kaufmann who developed innovative prefabricated buildings such as Su-Si designed a small temporary cardboard shelter that folds out of a hand-held carry case.

- The shelter, when unfolded, measures about 6ft x 3ft x 5ft high and weighs about 24 lbs:
  - The carry case is wrapped in a colored plastic sheet that is used as a protective cover over the shelter when completed.
  - There is enough room for one adult to lie down inside, and the cardboard floor offers some insulation from a cold ground below.
  - Fifty of these shelters were deployed on streets of Turin, Italy during the city’s Biennale Arte Emergente in 2002.



Carton House

Rigid Wall Systems

Brigata Tognazzi MOVE HOUSE

Polycarbonate House

This temporary dwelling was constructed of polycarbonate sheeting attached to a wooden frame positioned around it:

- The $16m^2$ structure included a small kitchen, shower, toilet, living room and sleeping area:
  - The dwelling was set on a concrete slab.
  - While self-supporting, insulation was required to be added to the polycarbonate sheets to keep it cool in hot weather.
  - The structure could be dismantled in hours and packed away for future use.

Rigid Wall Systems

Puzzle House was designed as a temporary dwelling to occupy a vacant building plot in Old Town of Seville, Spain.

- The structure was constructed like scaffolding to get around building codes and allow owners to use such dwellings for up to three months while waiting for permission to renovate existing properties or build new ones.

Installation in Seville, Spain

Santiago Cirugeda **MOVE HOUSE**

Puzzle House

The Modular Extendable Rigid Wall Structure (MERWS) serves as an expansion kit for the Army Standard Expandable ISO Shelter.

- The shelters are transported as panels and are erected on site to provide very large interior spaces:
  - Shelters are constructed from 40 individual paper honeycomb and aluminum skin panels that are strong and lightweight.
  - When attached to a two-sided expandable ISO, they can provide 1,150ft² of open space for command posts, hospitals, maintenance facilities and other applications.
  - They can be unpacked from a 20ft long ISO and assembled by four soldiers in less than four hours.
  - Accommodations include lights, a circuit breaker panel, a personnel door, and ECU interface and leveling jacks.

GICHNER SHELTER SYSTEMS

Modular Extendable Rigid Wall Structures

Rigid Wall Systems

Heikkinen- Komonen Architects

Heikkinen- Komonen Architects in Finland was commissioned by Kannustalo, Ltd., a building company, to design a prototype prefabricated house to be exhibited at the Tuusula Housing Fair in 2000.

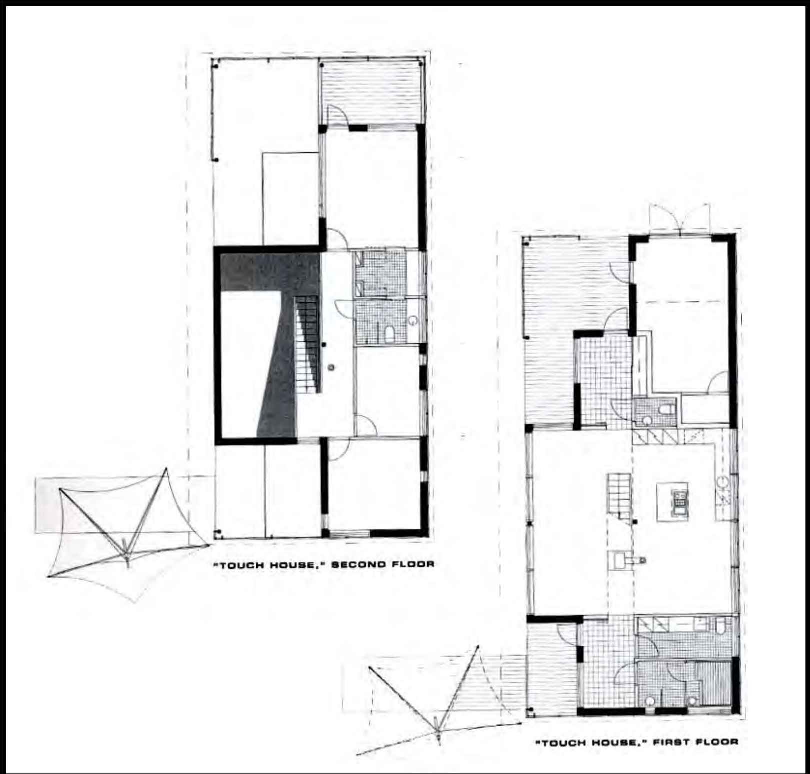
- The wood exterior of the home is made from large prefabricated wall units that are assembled at a factory:
  - The home has a refined exterior and interior that contrasts with the poor “cardboard box” image often associated with prefabricated houses.
  - Intricate wood slats that run outside the house create a design element that can be seen from windows all around the house lending an aesthetic effect.
  - A sail canopy was added as a special feature by the owners.

The Touch House

Rigid Wall Systems

Heikkinen-
Komonen
Architects

PREFAB MODERN



The Touch House

Rigid Wall Systems

CONSTRUCTED FACILITIES

PANEL STRUCTURES

Heikkinen-Komonen Architects

PREFAB MODERN

The Touch House

Rigid Wall Systems

CONSTRUCTED FACILITIES

PANEL STRUCTURES

The LV home designed by Rocio Romero for her mother in Laguan Verde, Chile (hence, “LV” House) is a kit house that can be built for $75,000-$120,000.

- The 970ft² house is provided as a factory-built shell that is internally outfitted/ finished by the owner’s contractor:
  - For $29,195, plus shipping costs, the shell is delivered to the site.
  - The owner’s contractor provides the concrete foundation and finishing materials.
  - A simple plan layout provides two small bedrooms and a living space with large windows in front.
  - The shell can be assembled by four people in less than a week.

The house kit provides six-inch thick exterior walls that are engineered to pass strict codes for high wind, snow and earthquake zones:

- There is only one structural wall between the bedrooms and living area.
- Although not designed to be attached, two or more LV homes could be joined to create a larger facility.

Rocio Romero **PREFAB MODERN**

The LV Kit House

Rigid Wall Systems

Rocio Romero PREFAB MODERN

An Open Living Space Offers Large Windows

The LV Kit House

Rigid Wall Systems

Rocio Romero

PREFAB MODERN

Rocio Romero refers to her Fish Camp House as a “camp structure”, or an “elegant tent”, to serve as a second house.

- The kit structure is intended for comfortable campouts in remote areas:
  - The interior opens up to the landscape with large sliding doors.

The Fish Camp House

Go to the list of contents

SECTION E :
SOFT TENSILE STRUCTURES

System Types

Soft fabric structures can be supported by rigid frames, such as familiar tent types, or by pneumatic pressure approaches. Popular advantages include compact transport, rapid and easy deployment, and large open volumes at low costs. As with constructed facilities, utility systems and functional user elements are add-ons following deployment.

- Tent-type systems include:
  - Mast-supported types
  - Frame-supported types

- Pneumatic systems include:
  - Air-supported types
  - Airbeam-supported types

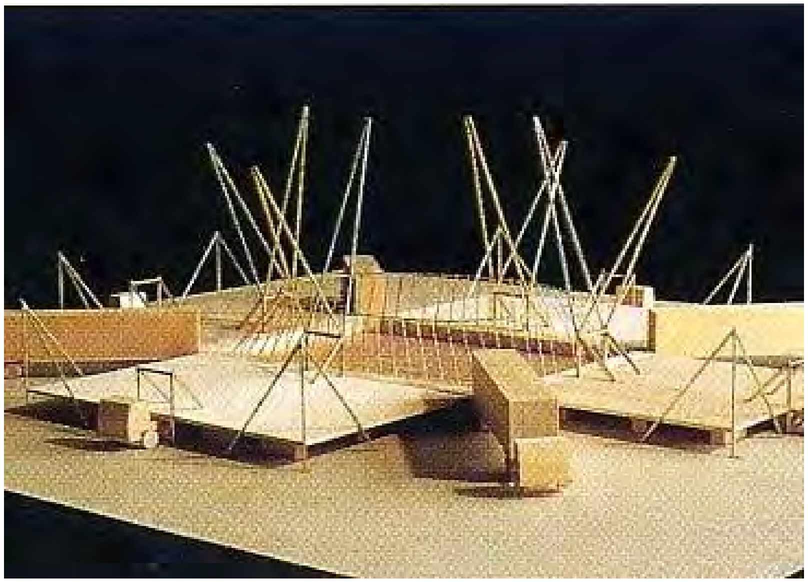
SOFT TENSILE STRUCTURES

TENT AND PNEUMATIC SYSTEMS

FTL Design Studio **MOBILE**

The Time for Peace Pavilion was proposed by artists Robert and Marion Einbeck as a mobile architectural facility on wheels, carrying its own structure, enclosure floors, and interiors from site to site.

- The primary element is a mast-supported tensile enclosure divided into five spaces dedicated to information, education, communication, art and reflection:
  - The Chamber of Reflection is the spatial centerpiece, and would contain an enormous art installation.
  - The pavilion's mobility and open spaces would also enable it to accommodate a wide variety of other event uses.

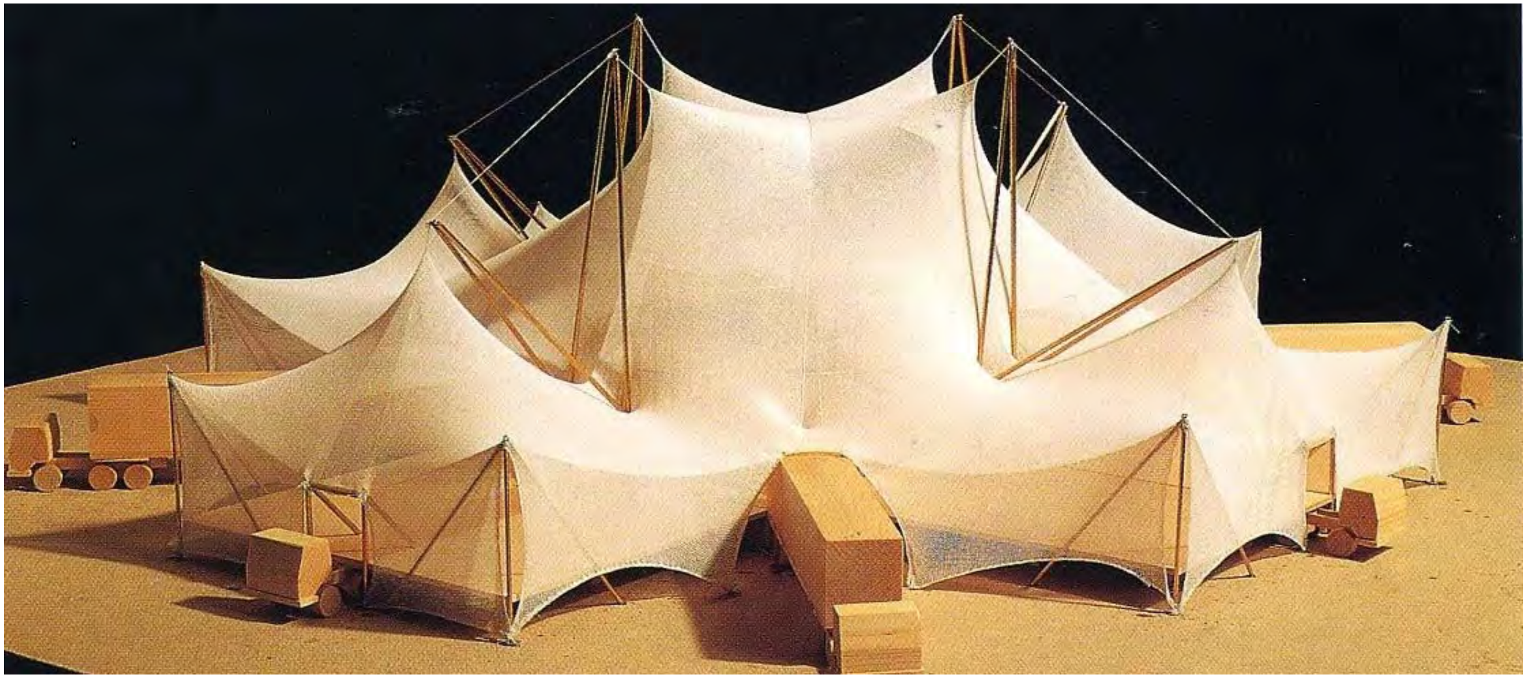


Time for Peace Pavilion Proposal

Mast-Supported Types

FTL Design Studio

MOBILE



Time for Peace Pavilion Proposal

Mast-Supported Types

SOFT TENSILE STRUCTURES

TENT SYSTEMS

Jan Kaplicy

This portable, low-cost, long-span structure was developed for emergency or disaster relief:

- The shelter is designed similar to a large umbrella, with 12 radial ribs that can be erected by 12 people in a very short time.

Umbrella-Type Long-Span Structure

Buro Happold **PORTABLE ARCHITECTURE**

In 1993 the Radha Soami Satsang Beas (RSSB) religious organization commissioned the development of a large shelter to house summer gatherings for up to 25,000 members in rural Bedfordshire, England.

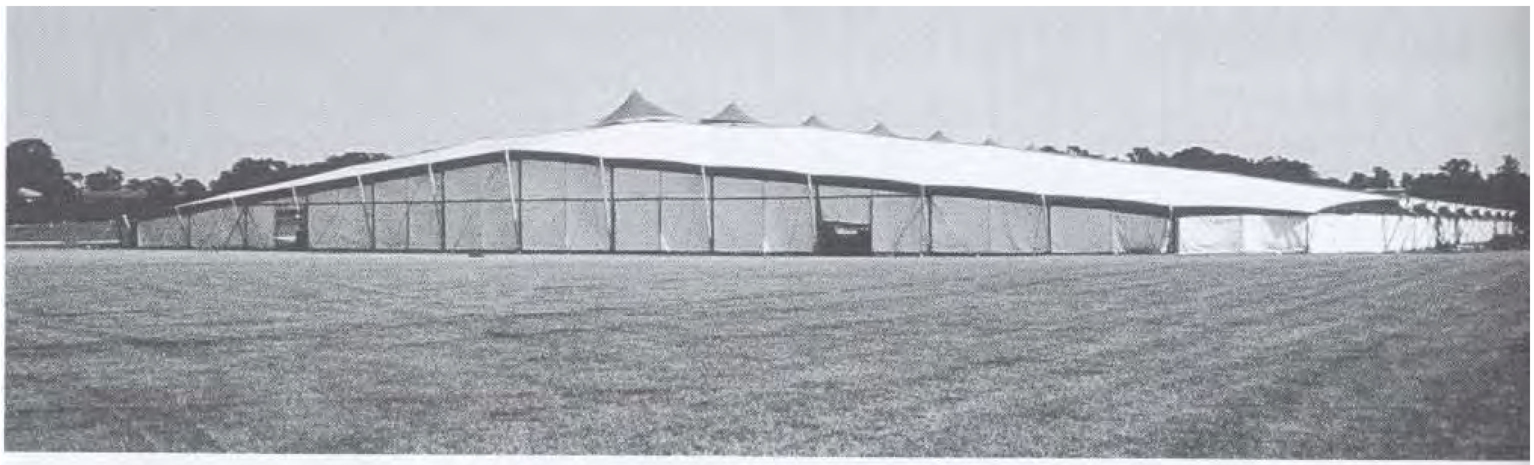
- A temporary tensile structure approach was selected because a permit for a permanent facility could not be obtained, and also because it would stand empty for all but two weeks of each year:
  - A single lightweight tension membrane was designed to cover 20,000 m² consisting of 60m x 15m panels.
  - The membrane was elevated from the ground by a series of minimal compression members with a tensegrity structure in the central section to provide a large clear span.

Radha Soami Satsang Center

Mast-Supported Types

Buro Happold

PORTABLE ARCHITECTURE



Radha Soami Satsang Center

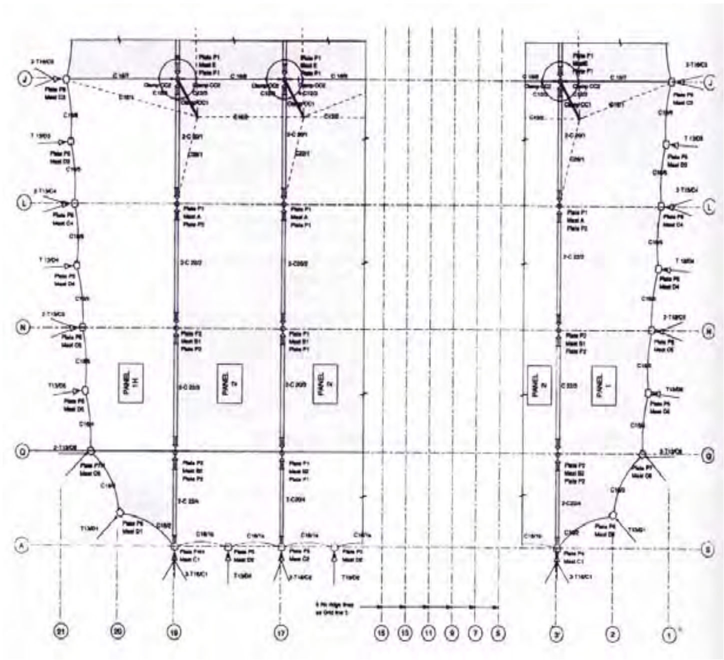
Mast-Supported Types

SOFT TENSILE STRUCTURES

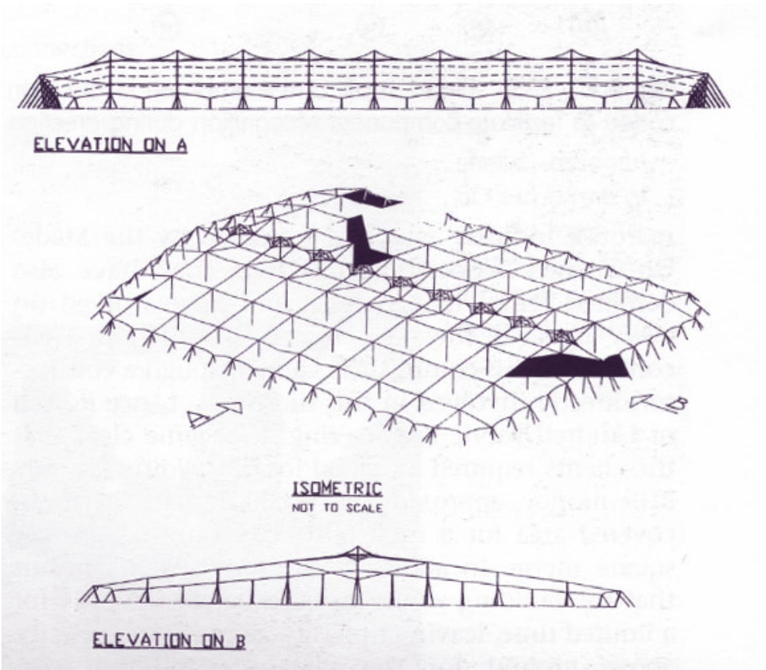
TENT SYSTEMS

Buro Happold

PORTABLE ARCHITECTURE



Mast and Membrane Layout Plan



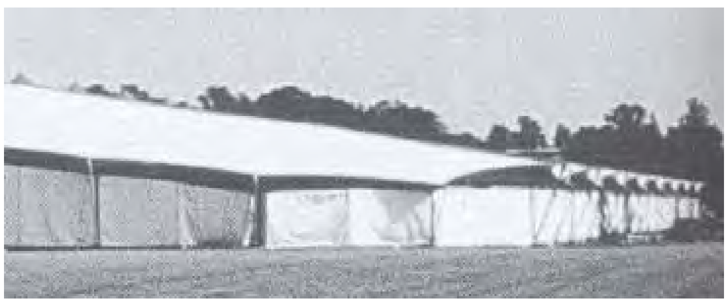
Radha Soami Satsang Center

Mast-Supported Types

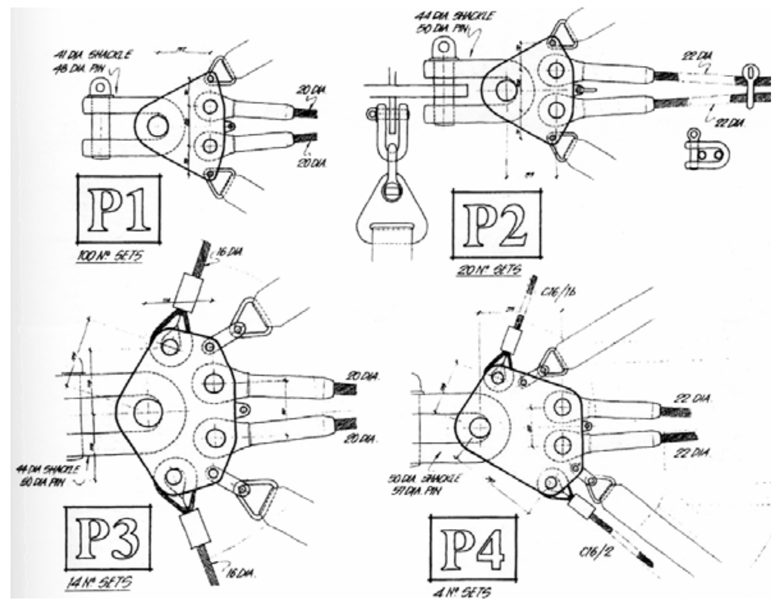
MS-SPACE ARCHITECTURE
SICSA

Buro Happold **PORTABLE ARCHITECTURE**

When the entire shelter is erected, the whole structure is tensioned and stiffened by stretching cables across the entire width, along with a continuous cable that skirts the membrane perimeter. It is designed to counteract upward wind forces which would otherwise lift the structure off the ground.



Lightweight Perimeter Masts Splay Outwards



Radha Soami Satsang Center

Mast-Supported Types

Buro Happold

PORTABLE ARCHITECTURE

Radha Soami Satsang Center Deployment

Mast-Supported Types

SOFT TENSILE STRUCTURES

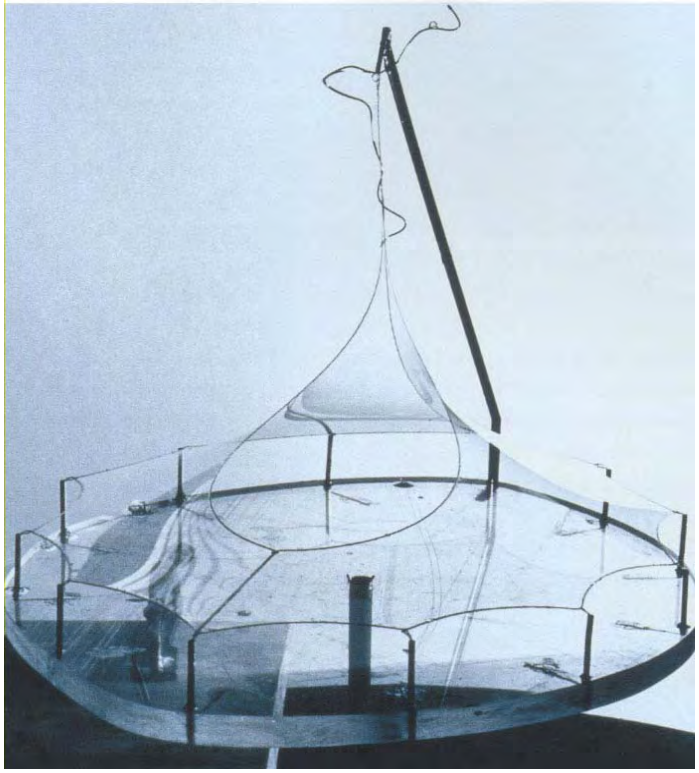
TENT SYSTEMS

Architect Frei Otto perfected pre-stressed cable-net systems which features suspended roofs comprised of crossed steel cables that curve against each other to distribute loads.

• Otto's 1968 Institute of Lightweight Structures (ILEK) building in Stuttgart provides 460 m^2 of transparent covering which admits light inside.

1968 ILEK Structure, Stuttgart

Frei Otto FEATHERWEIGHTS



Structural Model

Mast-Supported Types

Frei Otto

FEATHERWEIGHTS

Frei Ottos's 1967 Expo Pavilion in Montreal was covered by an 8,000 m^2 area of cable-supported membrane on masts up to 38 meters high.

Cable-Net Deployment

1967 Expo Pavilion

Mast-Supported Types

Frei Otto/
Gunther Behnisch

FEATHERWEIGHTS

Designed in collaboration with Gunther Behnisch, Frei Otto's 1972 Munich Olympic Stadium provided a 34,000 m^2 membrane roof supported by massive pylons.

Munich Olympic Stadium

Huge Acrylic Panels Cover the Roof

Mast-Supported Types

Various Emergency Modules were developed by Gregorio Brugnoli-Errazuriz and his architecture students at the Universidad Central de Chile in Santiago.

- The tent structures were designed as “instant dwellings” where traditional construction techniques for shanty settlements and squats are too slow:
  - Five dwellings were built using plastic tubes for structural framework, and plastic sheeting provides skins.
  - Module A was an open cubic space with smaller private compartments projecting from sides.
  - A transparent skin covers the core area, and an opaque black plastic provides privacy around the sleeping and dressing areas.

Gregario Brognoli-Errazuriz **MOVE HOUSE**

Emergency Module A

Frame-Supported Types

Gregario Brognoli-Errazuriz

MOVE HOUSE

Emergency Module B

Frame-Supported Types

Gregario Brognoli-Errazuriz

MOVE HOUSE

Emergency Module C

Emergency Module E

Frame-Supported Types

A family of small 2,3 and 4-soldier tents have been extensively used by the US Army and Marine forces to replace larger shelters that were too heavy to backpack into the field, and which took too long to set up.

- Many thousands of 2-man shelters (upper image) have been produced for the Marine Corps for use in desert and temperate climates:
  - Rigorous physical requirements include weight, volume and packaged size; withstanding snow loads, wind-driven rain and winds up to 40 mph; and undergoing multiple set-up/tear-down cycles without failure.
- US Special Operations Forces use a 3-Man "LEWS" shelter (lower image) in the extreme weather of arctic, desert and mountain regions:
  - This tent provides an additional 10 ft^2 of space, is vapor-permeable with a waterproof tub-style floor, and has roof and floor vents to minimize condensation build-up.

Army/ Marine Personnel Shelters

Frame-Supported Types

Ian Liddell created a small tent shelter for Roger Mear and his two companions for their 70 day walk across Antarctica to the South Pole in 1985-86.

- The tent was designed to be carried on a 2.4 meter-long sledge in a partly assembled form:
  - The umbrella-type structure was packaged as a long bundle with six glass-fiber poles contained within a lightweight, high-strength membrane.
  - Poles were attached with a removable pin (for failure replacement) to an aluminum radial element at the tent top.
  - When fabric was pulled down, its curved shape sprung the poles into compression, and pole bottoms were then pulled out with a continuously attached ground sheet creating a 2.5-meter diameter floor plan.

The Antarctic Expedition Tent skin was made from Gortex fabric which allowed inside moisture to pass through, combined with a nylon outer layer and a PTFE skin bonded to the underside. A lightweight inner membrane was also used as an air buffer zone to help raise internal temperatures.

Ian Liddell **PORTABLE ARCHITECTURE**

Antarctic Expedition Tent

Frame-Supported Types

The Modular General Purpose Tent System (MGPTS) was developed for the US Army to replace older types of military tents.

- More than 2,000 MGPTSs have been fielded around the world, including use for Operation Iraqi Freedom:
  - Designed to meet the highest performance specifications ever established, the tents can sustain wind gusts over 100 mph and will not leak even under hurricane conditions.
  - The tents are "blackout capable" so that with lights on at night and doors closed, no light will leak out.
  - The structures are designed for extreme climates, and can support substantial snow loads.

Modular General Purpose Tent System (MGPTS)

Frame-Supported Types

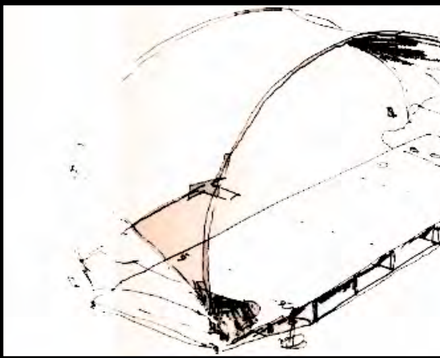
FTL DESIGN STUDIO

Modular General Purpose Tent System (MGPTS)

Frame-Supported Types

The MOMI hospitality tent is a lightweight relocatable structure that can be erected or dismantled by six people in about two days.

- It has a raised floor assembly of aluminum panels containing electrical services that rests upon steel beams leveled by jacks.
  - A white Tenara fabric membrane skin is stretched between pairs of inclined arches formed with 32mm rods.



Rib arches are stabilized by struts and cables

The MOMI Tent

Frame-Supported Types

SHELTER SYSTEMS

Shelter Systems provides a variety of lightweight portable shelters including geodesic domes (or "yurts").

- The yurts range from 14ft-31ft diameter and are made of strong, tear-resistant fabric which allows outside daylight in for illumination:
  - The structures can be set up by one person in 30 minutes without tools by placing poles into factory-attached connectors spaced evenly over the cover.
  - The poles bend slightly when inserted to tighten the cover into a wind and waterproof shelter.
  - Shelters can be repositioned at the site without disassembly, and taken down in five minutes by simply removing the poles and rolling up the covering.
  - The poles attach on the outside of the covering in a manner that prevents direct contact between the frame and skin to avoid rubbing that can wear holes in the cover.

Portable Geodesic Yurts

Frame-Supported Types

SHELTER SYSTEMS

Portable Geodesic Yurts

Frame-Supported Types

SOFT TENSILE STRUCTURES

TENT SYSTEMS

SHELTER SYSTEMS

Portable Geodesic Yurts

The yurts are very strong because the curved shape has no corners to create weak points.

Covers are formed of shingled panels which overlap each other by 6 inches, making structures leak-proof, yet allowing them to breathe:

- Build-ups of moisture are driven out through the overlapped panels by vapor pressure and do not condense inside the tents.
  - Patented “Grip Clips” fasten the covers to frames, and also attach the shingled panels together in a manner that is stronger than sewn seams or grommets that would puncture the covers.
  - The clips grip larger surface areas of material to prevent wind from tearing the tents.

Frame-Supported Types

Shelter System's yurts are made of strong, tear-proof woven rip stop film that will not rot or mildew.

- The covering is manufactured in three layers which are bonded together:
  - Covers are UV-stabilized to withstand up to three years of full sun exposure, and are supported by long-lasting UV-stabilized Class 200, 1 ¼ inch diameter PVC tubing.
  - Translucent white covering creates a bright interior, transmitting 60% of outdoor light.
  - Standard yurts come with four clear vinyl windows above doors, and extra strong yurts have translucent windows that transmit more light than glass, but are frosted so that you cannot see clearly through them.

SHELTER SYSTEMS

Portable Geodesic Yurts

Frame-Supported Types

Titan Structures are mass-produced in 100ft-180ft wide clear spans using two-chord steel trusses in parallel configuration.

- The structures are modular, extendable in length, and clad with structural fabrics.

FTL DESIGN STUDIO

The Tents Meet Permanent Bldg. Codes

The Titan Tent

Frame-Supported Types

FTL DESIGN STUDIO

Construction Uses “Off-the-Shelf” Trusses

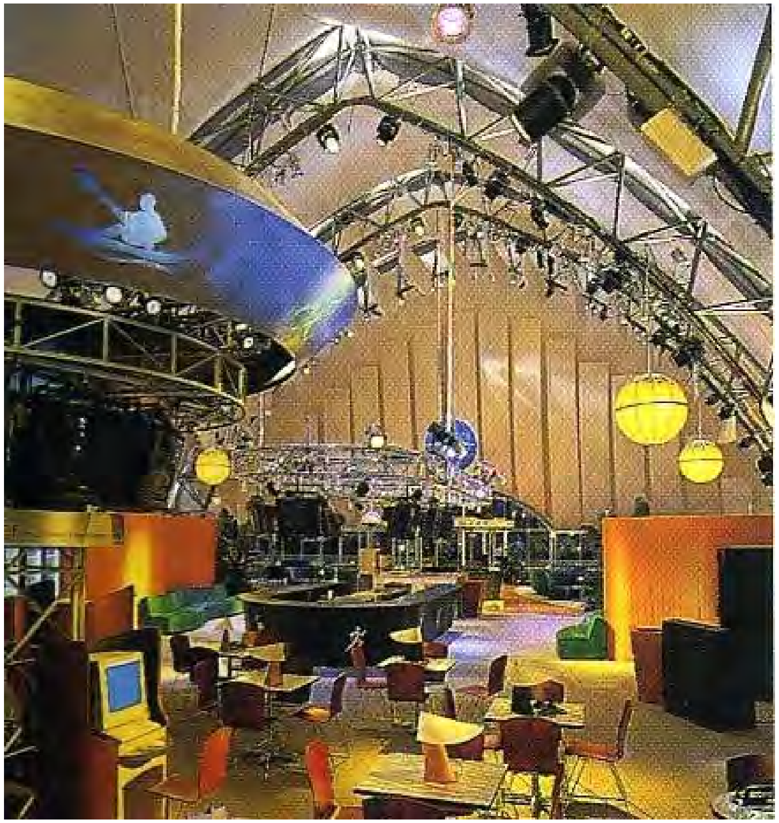
The Titan Tent

Frame-Supported Types

The AT&T Global Olympic Village structure was designed and constructed for the 1996 Summer Olympics in Atlanta, and subsequently traveled to Olympic venues in Nagano (1998), Sydney (2000) and Salt Lake City (2002).

- The $30 million, 9,000 ft² complex was comprised of three buildings:
  - The "village" incorporated two-storey relocatable glass curtain walls, relocatable interior elevators, and a second-storey bridge between buildings.
  - The form of the village pavilions was established by a series of Gothic truss arches carrying a transparent fabric clear storey colored with more than 2,000 theatrical lights.
  - Images from live concert events were projected 200 ft wide onto the outside of the building fabric.

FTL DESIGN STUDIO



AT&T Global Olympic Village

Frame-Supported Types

FTL DESIGN STUDIO

AT&T Global Olympic Village

Frame-Supported Types

SOFT TENSILE STRUCTURES

TENT SYSTEMS

Pavilion structures incorporated steel truss arches, a PVC polyester membrane, glass and metal curtain walls, custom holographic walls, integrated lighting and special furniture.

FTL DESIGN STUDIO

AT&T Global Olympic Village

Frame-Supported Types

Shigeru Ban **FEATHERWEIGHTS**

Shigeru Ban's Curtain Wall House, created in Tokyo (1995), uses actual fabric curtain walls made of fabric.

- The light structure nests upon three delicate columns, and appears to float over the site

- When desired, the walls can be simply pushed away to open the interior to the surroundings.

- The open space is covered by a greatly protruding flat roof, which shades the lower balcony floor

Frame-Supported Types

The Powerhouse UK Pavilion created in 1998 is comprised in large part of four 16 m diameter air-cushion drums supported by steel frames for stability.

- Rather than develop a pure inflatable or air-supported building, it was decided to separate the load-bearing structure from the envelope for depressurization safety reasons:

  -The silver-coated PE-PVC cushions provide a taut enclosure.

  -The four air-cushion drums are arranged like clover leaves and lit in bluish light.

Doug Branson and Nigel Coates **FEATHERWEIGHTS**

Powerhouse UK Pavilion, London

Frame-Supported Types

Doug Branson and Nigel Coates

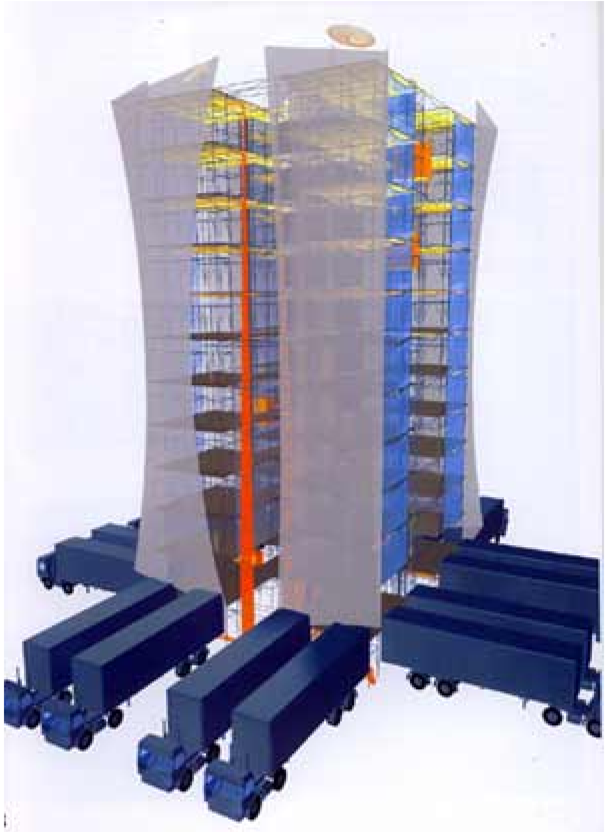
Powerhouse UK Pavilion, London

Frame- Supported Types

FTL DESIGN STUDIO

This structure was proposed for temporary use on vacant urban sites for durations of six months to two years.

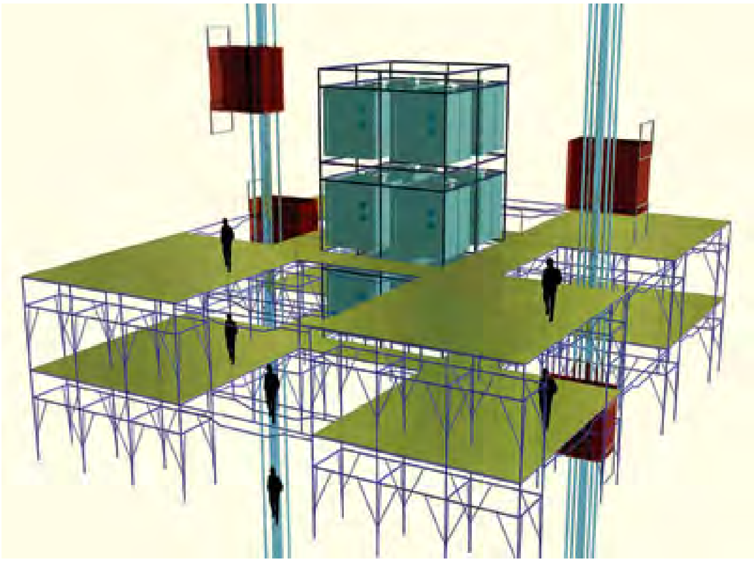
- The building would principally be comprised of an erectable scaffold with standard clip-on floor planks, attachable construction industry elevators, stackable event industry toilets and a double-layered fabric curtain wall:
  - All infrastructure (power supply, water / waste lines and HVAC) would be housed in event industry truck trailers located at ground level.
  - All services and utility risers would utilize flexible conduits and ducts attached as risers.
  - Building width and height ratio proportions would be designed to enable assembly on a flat site without foundations, yet resist overturning moments from wind and dead loads.



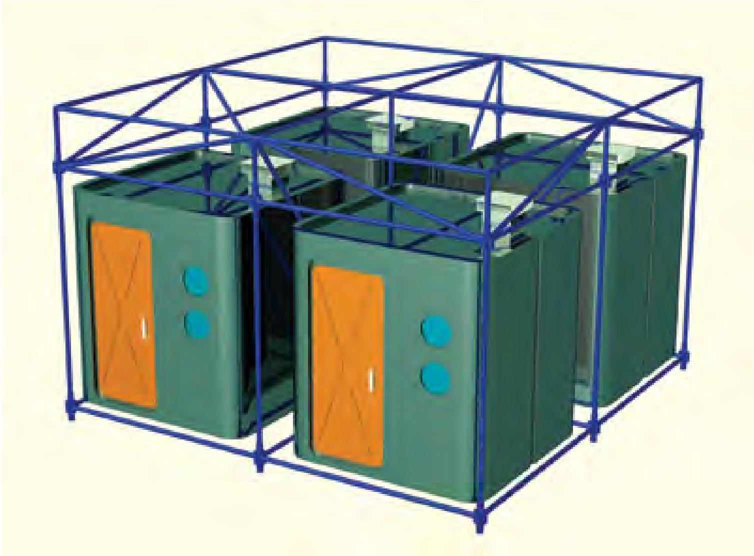
Recyclable Portable Fabric Skyscraper

Frame-Supported Types

FTL DESIGN STUDIO



Skyscraper Floor



Bathrooms

Recyclable Portable Fabric Skyscraper

Frame-Supported Types

Benno Bauer's Culture Center in Pucheim, Munich was created as an events hall for up to 800 people.

- The 1,000 m^2 facility is covered by an arched fabric roof constructed of wood truss frames covered with a Teflon membrane.
  - Bauer was awarded the 1999 International Textile Architecture Prize for his design.

Benno Bauer **FEATHERWEIGHTS**

Culture Center in Munich

Arch-Supported Types

Benno Bauer

FEATHERWEIGHTS

Membrane Attachment to the Ground

Culture Center in Munich

Arch-Supported Types

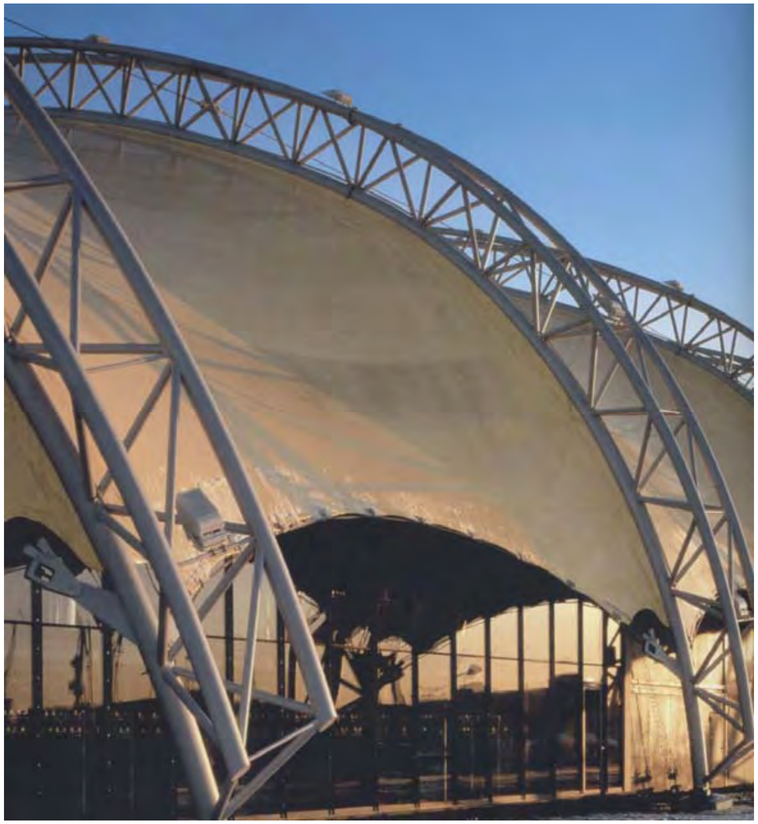
Klaus Latuske **FEATHERWEIGHTS**

Klaus Latuske's arched hall design was proposed as a transportable structure for musical events in 1997, but was made permanent as a theater in Hamburg Harbor in 2001.

- Five steel-braced arches span 55 meters, forming a column-free space with an unimpeded stage view.

- Each of the five trusses could be taken apart into five pieces, and snap bolts in the foundation allowed the structure to be moved.

Transportable Element Hall Design



Music Theater in Humburg

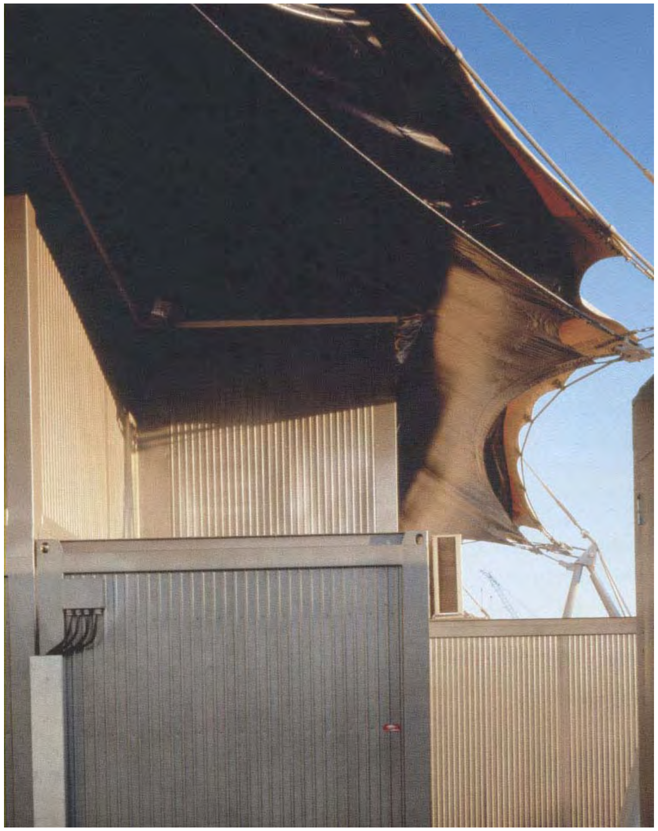
Arch-Supported Types

Klaus Latuske **FEATHERWEIGHTS**

Latuske's Music Theater was designed to accommodate an audience of 1,400 people in comfort.

- Originally planned as a very lightweight building, the structure was later modified in ways that added mass and prevented relocation:

- In 1991 the tent roof was modified to provide a two-membrane covering with a 30 cm air space to absorb sound and improve weather insulation.
- An under-stage and 25 m high fly tower were added, along with an additional balcony which increased capacity to 1,926 seats.
- A five storey management building was constructed next to the stage, along with a restaurant and ferry landing pier with direct access to the foyer.



Music Theater Additions

Arch-Supported Types

Frei Otto's lattice arch structure, used at the 1975 National Garden Show in Mannheim, Germany, was comprised of 72 kilometers of wood lattice connected using 38,000 bolts.

Otto provided consulting support to Shigeru Ban for his Expo 2000 Pavilion in Hanover which applied similar construction.

Frei Otto **FEATHERWEIGHTS**

1975 National Horticulture Show

Shigeru Ban **FEATHERWEIGHTS**

Expo 2000 Pavilion in Hanover, Germany

Arch-Supported Types

The Portable Fresh Air Bay is designed primarily for the mining industry to provide a safe refuge and shelter from hazardous gases, toxic smoke from fire, or any kind of substandard air that imposes a threat:

- The unit is connected to compressed air, and inflates in minutes to provide high interior pressure:
  - Two interior valves ensure a constant fresh airflow.
  - The portable 5.5 kg unit can be comfortably carried in a backpack and is reusable.
  - Fabric construction is strong and flame-retardant.

Portable fresh Air Bay

Air-Supported Types

Large-span buildings supported by internal air pressure offer efficient uses for sports stadia, exhibition spaces and other purposes.

- Festo's Airquarium that was developed as a multipurpose exhibit and event environment, is a representative example:
  - The 32 m diameter air-supported dome uses a Vitroflex membrane that combines high translucency and strength characteristics.
  - In event of fire, the synthetic skin releases only a non-toxic vapor of water and vinegar.
  - The entire structure can be transported in two 6 meter standard containers, one holding modular HVAC, air pressure control and power generator units; the other containing the dome, an airlock and a foundation membrane.
  - The building can be installed by six people in about one week.

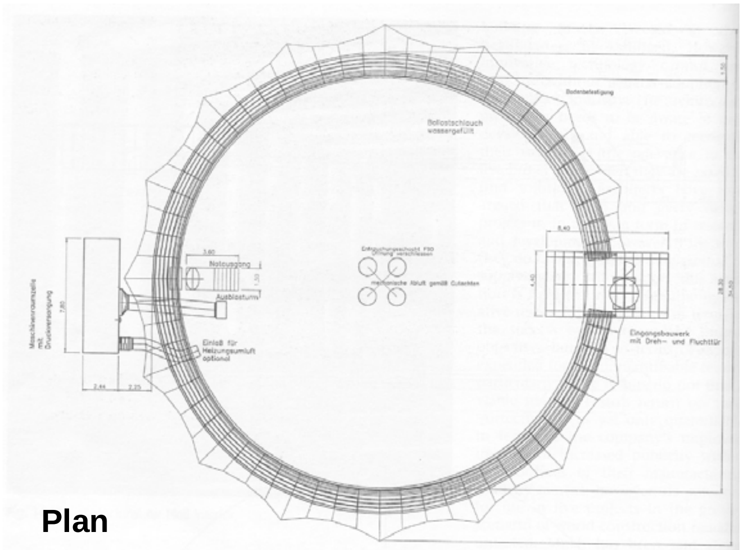
Festo **MOVE HOUSE**

Airaquarium, Bonn, Germany

Air-Supported Types

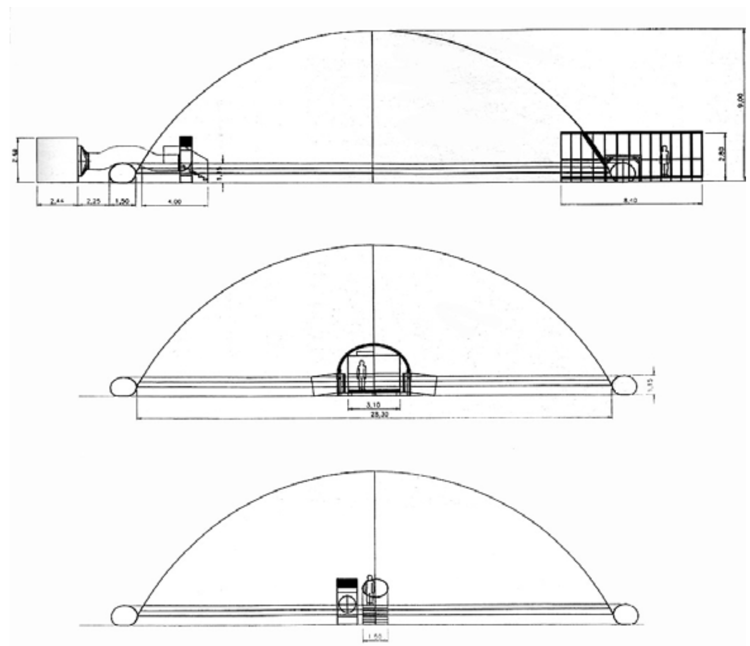
Festo

PORTABLE ARCHITECTURE



Plan

The structure is anchored to the ground by filling a tubular torus at its base with water. A main air-locked entrance cuts through the torus to enable passage of large vehicles.



Airaquarium, Bonn, Germany

Air-Supported Types

The first Colourpsace prototypes were developed by Maurice Agis, a sculpture teacher at Goldsmith's College, London between 1970-72.

• The first structure consisted of a series of different shaped inflatable spaces, each expressing a distinctive primary color:

- The shapes were linked by tunnels and surrounded by a perimeter circular tube.
- Skins were made of PVC inflated by a series of commercial electric blowers.
- Sponsored by the British Arts Council, the first installations traveled to more than 30 locations around the UK.

Maurice Agis

Colourspace Prototype, London

Maurice Agis developed several different Colourspace variations.

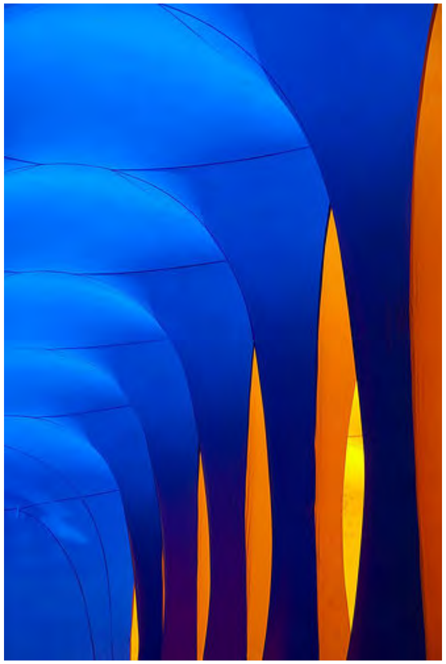
- One consisted of 68 identical Ovid cells, each measuring 3 m² on plan, and 3.5 m high:
  - The entire structure covered an area of 900 m².
  - Construction used 333 mm thick PVC sheets formed together with a combination of glued and taped joints made at the site.
  - Intended only for purposes of artistic experience, the enclosures did not provide HVAC systems or fire/smoke protection features required for more utilitarian building applications.
  - Visitors were required to remove shoes to avoid damaging the structures.

Maurice Agis

Colourspace Exhibtion

Air-Supported Types

Maurice Agis **PORTABLE ARCHITECTURE**



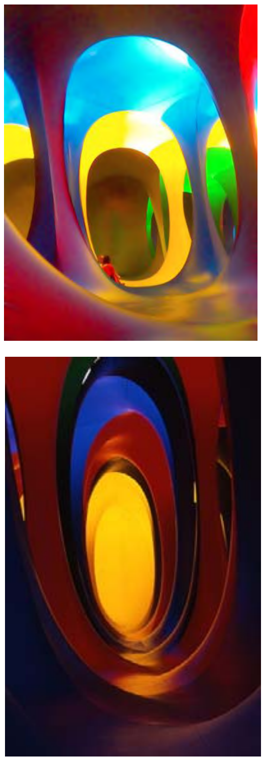
Dreamspace

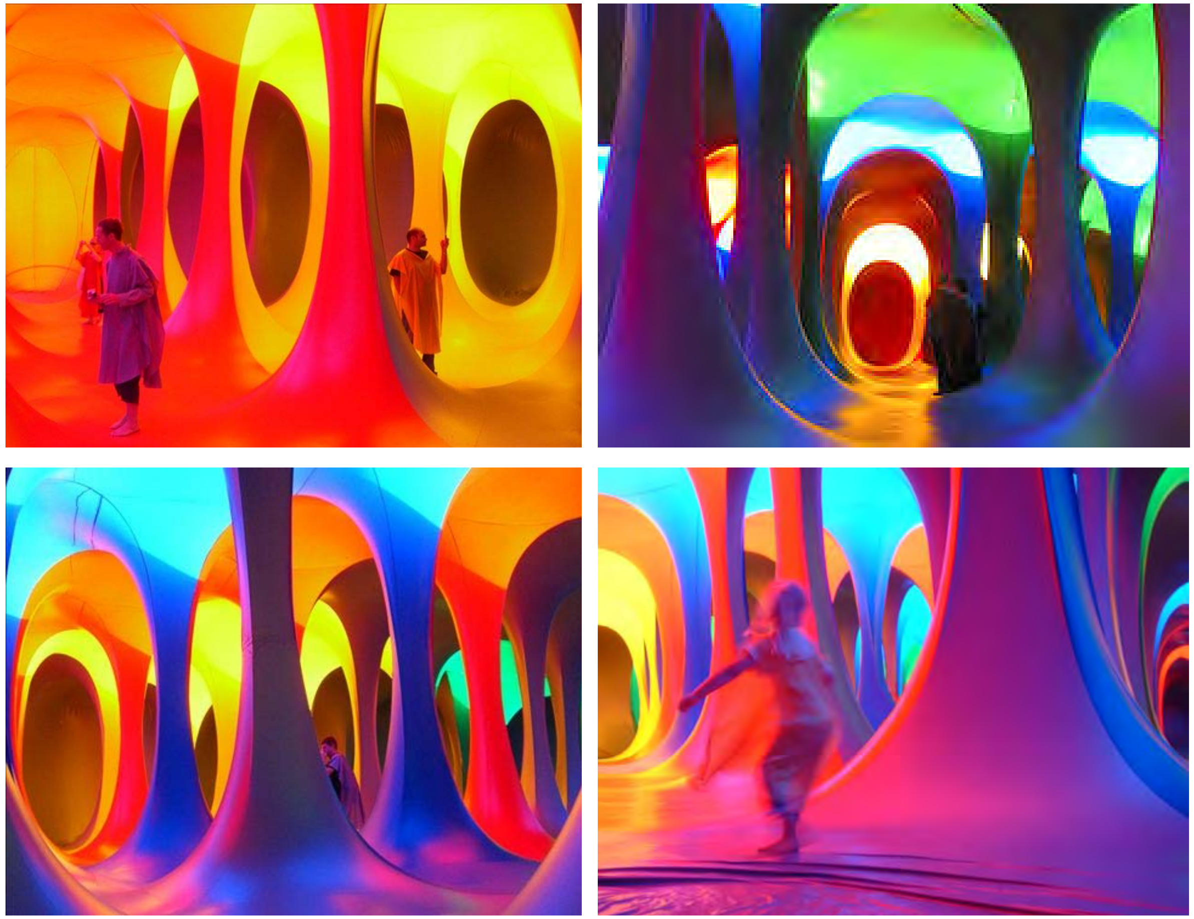
Activity Within Dreamspace

Dreamspace Aerial View

Air-Supported Types

Maurice Agis





Dreamspace Interiors

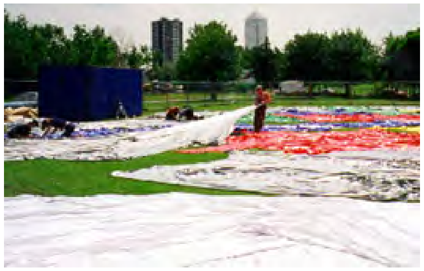
Air-Supported Types

PORTABLE

ARCHITECTURE

Maurice Agis


Dreamspace Being Unfolded




Dreamspace Being Setup


Dreamspace Being Delivered

Air-Supported Types

All habitable structures used in space are essentially air-supported (pressurized) enclosures, including some types currently being developed that have soft multi-layer walls.

- These "inflatable" pressure vessels can be folded into relatively compact bundles for launch, and provide generous interior volumes when deployed that greatly exceed "hard" module capabilities:
  - Bigelow Aerospace, a Las Vegas company, is developing inflatable modules to serve as orbiting hotels for space tourism.
  - The company also hopes to provide NASA with habitat systems for the Moon and Mars.

Air- Supported Types

BIGELOW AEROSPACE

Bigelow Aerospace is working with NASA and a variety of contracting organizations:

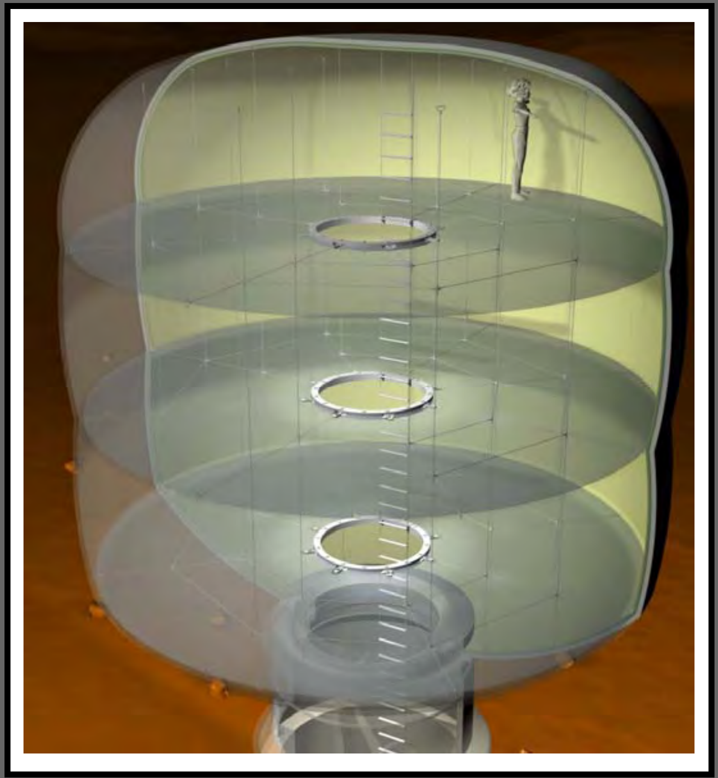
- The company holds 2 license agreements with NASA:
  - an exclusive license for 2 TransHab patents;
  - a license for radiation shielding with exclusive and non-exclusive contracts.
- Bigelow is developing ways to fold/package soft materials around a module's aluminum core to ensure that creases and critical seals such as windows don't leak when pressurized.

Module Inflation
The 7 layer module wall will be pressurized at 10 psi (compared with 14.7 psi for ISS).

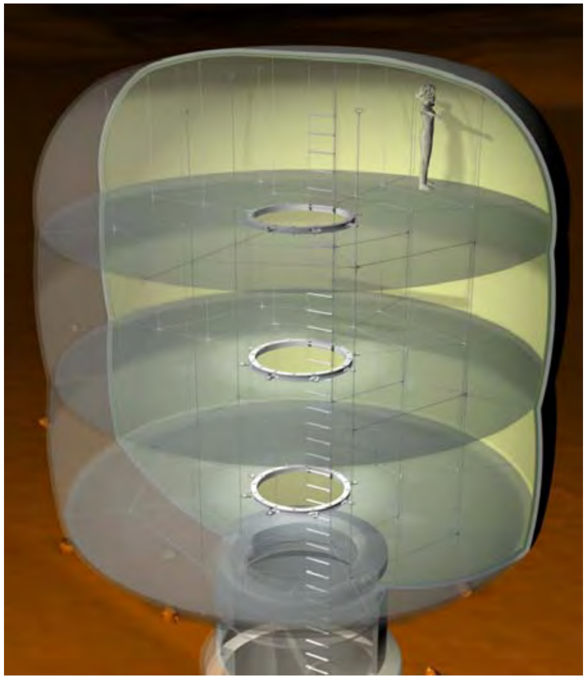
Air- Supported Types

SICSA has studied and conceptualized inflatable space structures over a period of more than two decades. One proposed design deploys interior floors automatically:

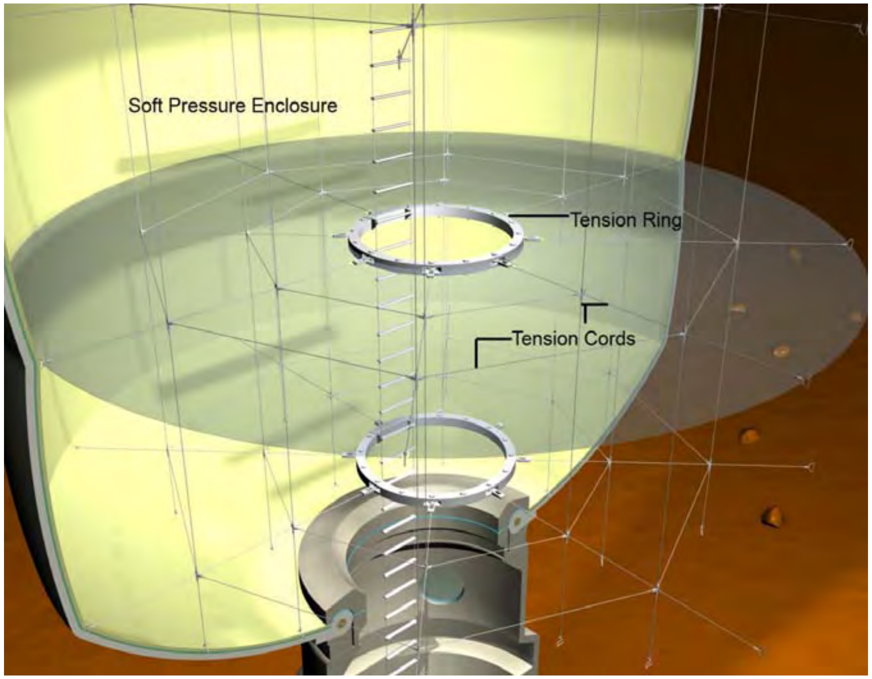
- An axial “web” of tension cables support floor membranes that are integrated and folded within the inflatable enclosure package prior to launch.
- Vertical cables, in combination with the horizontal web, restrain the deployed envelope shape and provide attachment points for utility systems and equipment.



Air- Supported Types



Pop-Out Internal Structure

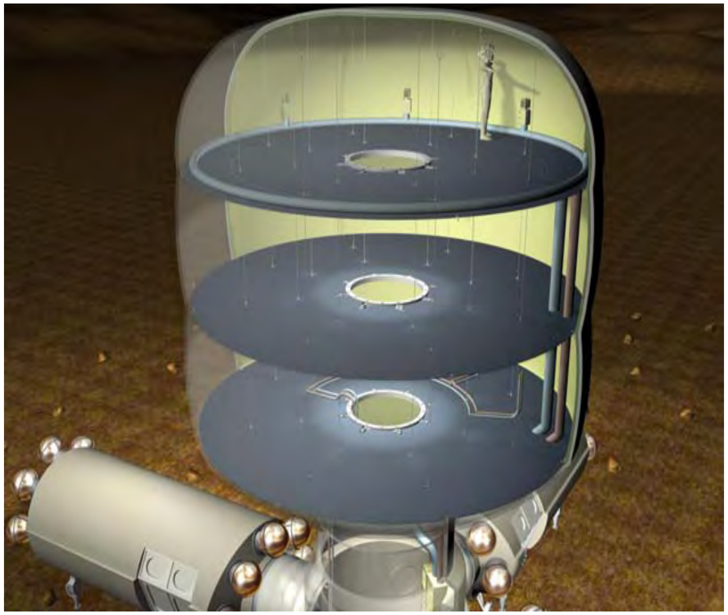


Typical Floor Structure

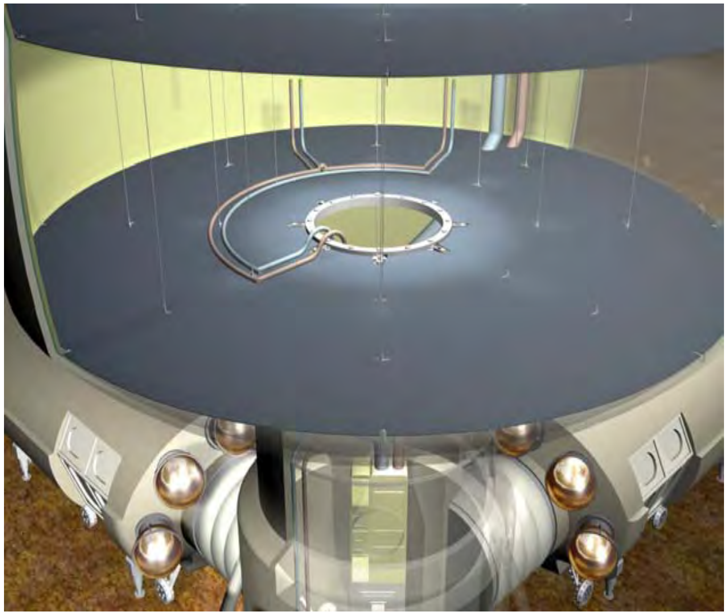
Air- Supported Types

SOFT TENSILE STRUCTURES

PNEUMATIC SYSTEMS

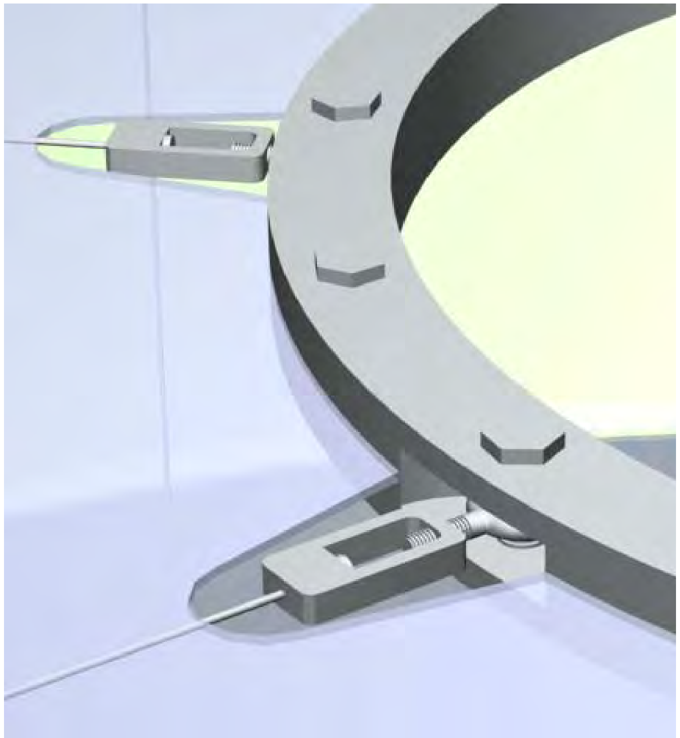


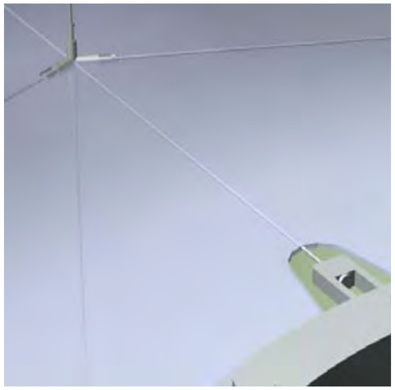
Three Level Scheme

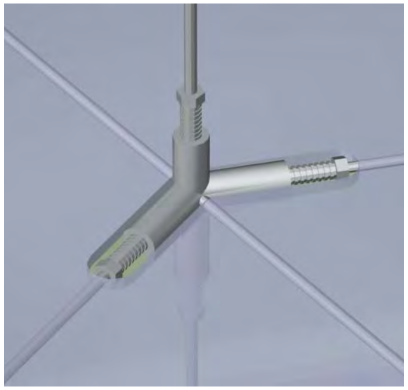


Lower Level Structure & Utilities

Air- Supported Types







Central tension rings accommodate vertical circulation between interior levels and offer attachment fixtures for utility risers and equipment. Turnbuckles enable tension chords to be adjusted in order to minimize floor “trampoline” effects.

Air- Supported Types

Inflatable and Conventional Module Complex

Inflatable Mars Lab Concept

Air- Supported Types

Inflatable Module Interiors

Air- Supported Types

SOFT TENSILE STRUCTURES

PNEUMATIC SYSTEMS

Airbeams are replacing metal and other hard structures conventionally used as tent frames for many applications.

- Use of these pressurized textile approaches can reduce weight and erection operations/ time.
  - Airbeams are typically manufactured by continuously braiding or weaving a high-strength fabric sleeve over an air-retention bladder
  - The technique creates seamless high-strength durable tubes ranging from 2-20 inches in diameter set at pressures which correspond with support requirements
- Each collapsible tube has a built-in valve for fill-up from tanks or air compressors.

Airbeam Technology

Airbeams

Airbeam- Supported Types

The Chemically and Biologically Protected Shelter System (CBPSS) is a highly portable unit designed to provide a contamination-free, environmentally-controlled work area for military medical field treatment teams.

- The 300 ft^2 semi-cylindrical airbeam-supported soft shelter mounts on the back of a dedicated trailer, along with a 10 kW tactical quiet generator for power:

- Four people can inflate the CBPSS in four minutes, and make it fully operational in less than 20 minutes.

- A hydraulically-powered Environmental Support System provides heating, cooling, airbeam inflation, CB filtration and ventilation.

- Multiple CBPSS units can be complexed together to expand capacity.

Medical Treatment Unit

Airbeam-Supported Types

Medical Treatment Unit Interiors

Airbeam-Supported Types

SOFT TENSILE STRUCTURES

PNEUMATIC SYSTEMS

Medical Treatment Unit Deployment Sequence

Airbeam- Supported Types

SOFT TENSILE STRUCTURES

PNEUMATIC SYSTEMS

The Future Medical Shelter System (FMSS) is an advanced shelter designed to be the next-generation Chemically Protected Deployable Medical System (CP-DEPMEDS).

- First demonstrated in 2003, a 64 ft long shelter can be set up in 15-20 minutes by four people (compared with about 40 minutes and 18 people required to set up a conventional tent of equal size):

  - Each structure incorporates four airbeams per 32 ft FMSS section which are inflated to 40 psi via a commercial air compressor.

  - The shelters are less than half as heavy as standard tents (1,200 lbs vs. 2,700 lbs)

  - Shelters are anchored to the ground with stakes for stability

Vertigo, Inc.

Future Medical Shelter Systems

Airbeam-Supported Types

The Transportable Maintenance Enclosure Project (TME) was undertaken in response to US Army interest in having a quickly deployable, large area shelter for helicopter maintenance.

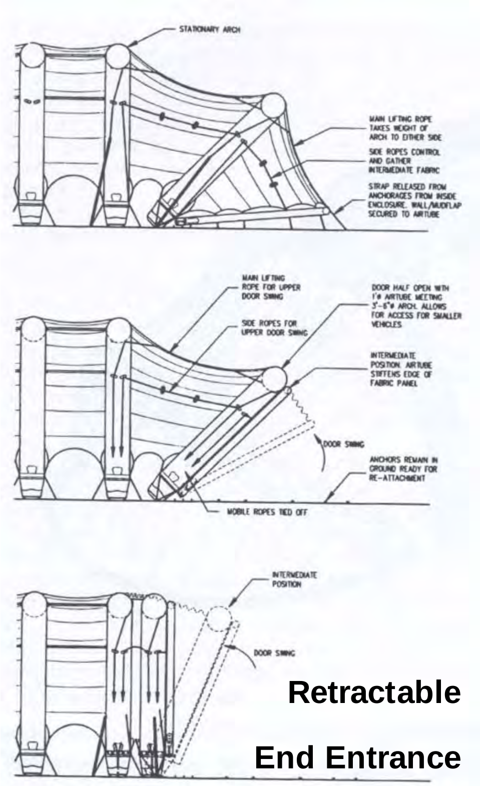
- FTL Happold was commissioned to design a relocatable hangar that would be air-transportable, weigh less than 900 kilograms, contain a space 9 m x 30 m x 6.7m high, be capable of being installed in less than six hours, and be operable under desert and arctic conditions:
  - The design solution provides a retractable end entrance offering full access to the entire volume
  - PVC-coated polyester structural arches are held down to the surface using webbing belts strapped to ground anchors.
  - Air pressure within the arch tubes is only 5 psi (about 1/7 of standard tire pressure).

FTL Happold PORTABLE ARCHITECTURE

Transportable Maintenance Enclosure

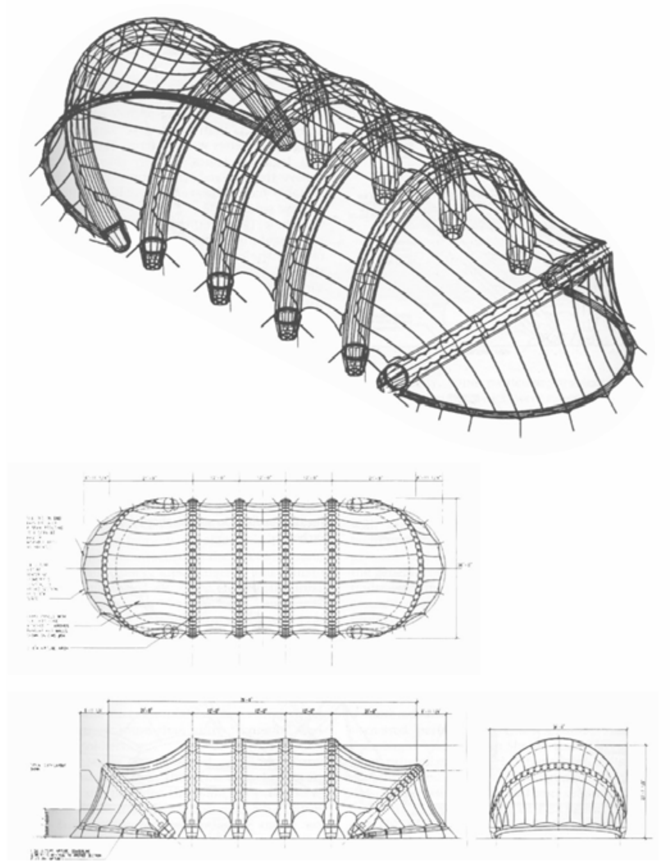
Airbeam-Supported Types

FTL Happold **PORTABLE ARCHITECTURE**



Retractable

End Entrance



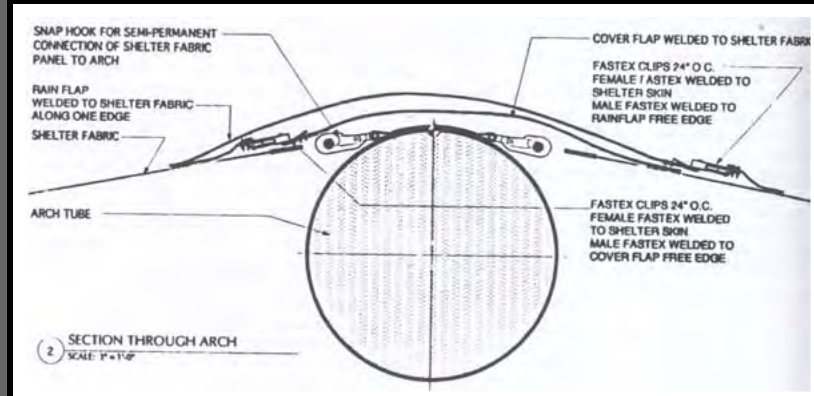
Transportable Maintenance Enclosure

Airbeam-Supported Types

SOFT TENSILE STRUCTURES

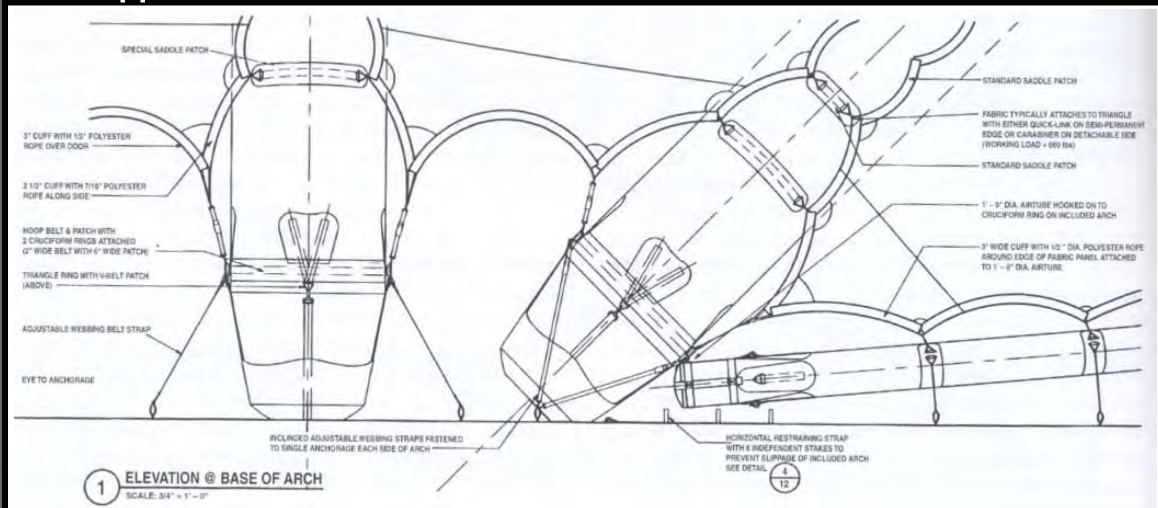
PNEUMATIC SYSTEMS

PORTABLE ARCHITECTURE



FTL Happold

TME airbeams are 42 in diameter tubes spanning about 30 ft to a height of about 10 ft. All covering membranes are overlapped for environmental control and black-out purposes.



Transportable Maintenance Enclosure

Airbeam-Supported Types

Cocoon is a small, lightweight mini-tent that can be inflated using a standard hand pump or gas cartridge.

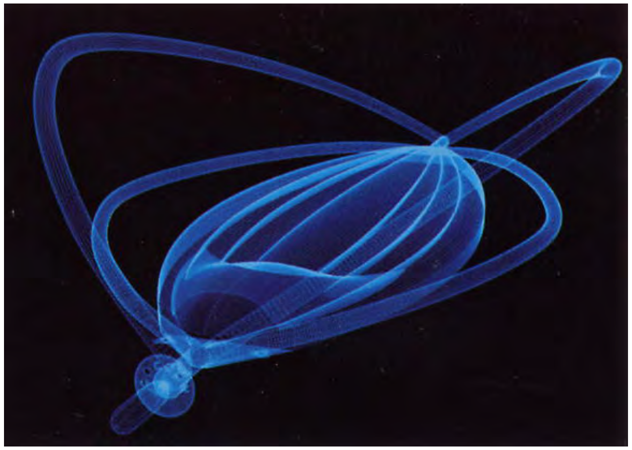
- The airtube-type unit can be used for leisure sport and travel, and also for rescue and disaster circumstances.
  - The translucent airbeam tubes allow daylight to enter, and fluorescent safety lights can provide illumination at night.
  - An outer shell is made of multi-layer sheeting that reflects body heat back into the tent, while also repelling low temperatures from the surrounding environment.
  - An inflatable mattress also functions as a ground base thermal insulation device.

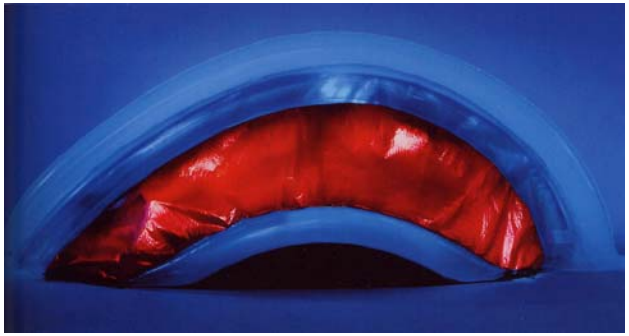
Festo

Cocoon

Airbeam-Supported Types

Festo





Cocoon

Cocoon is easily transportable due to its small packaged volume and weight.

Simple erection takes place by rolling out the tent, inflating the pneumatic structure, and then folding up the airbeams:

- A roll of standard adhesive tape is provided for easy repairs.
- A 100 micron-thick polyurethane sheet enclosure provides a cover.
- The base sheet is fabric-reinforced to prevent damage when erected on rough ground.
- All materials are bonded by thermal impulse welding so that no adhesives are required.

Airbeam-Supported Types

Hans-Walter Muller is a German architect who has created a variety of air-supported structures including theaters, circus tents, exhibition halls, an aviary, a church and his own home/studio dwelling.

- His multicolored home sits at the edge of a forest in La Ferte-Alais just south of Paris.

- The house has a 210 m^2 floor area, and the ceiling extends over 4 m high.
- Surrounding trees cast shadows across the walls to create an ever-changing pattern of light, and to shade areas inside.

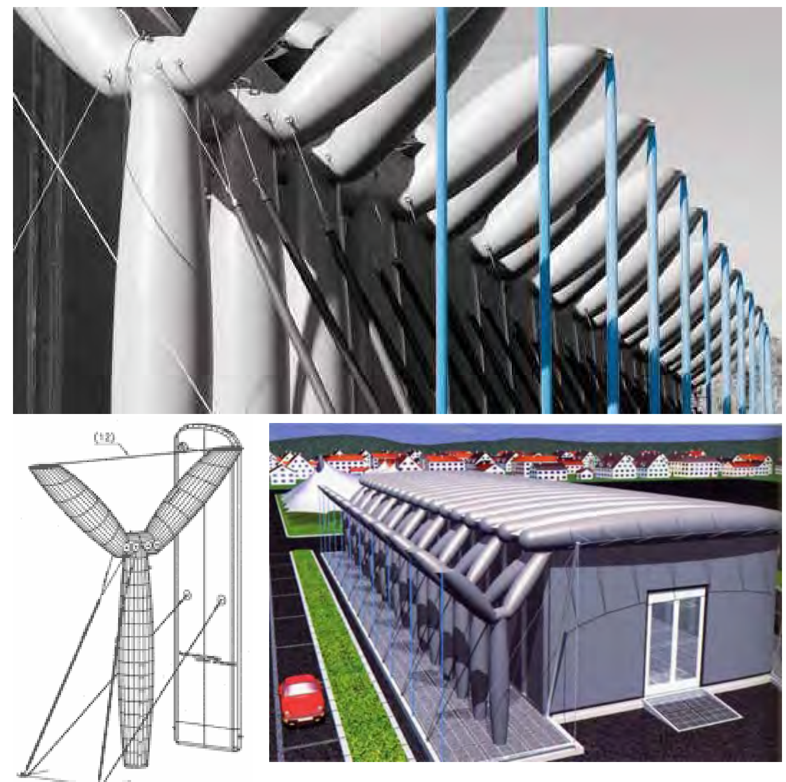
Inflatable Home-Studio

Airbeam-Supported Types

Festo and the Pneumatic Structures Group at the University of Newcastle upon Tyne created an Exhibition Hall building that utilizes airtybes for structural support.

- The load-bearing structure uses 40 Y-shaped columns and 36 wall components featuring double-wall fabric with flame-inhibiting elastomer coatings:
  - The inside of the hall is 6 meters tall with a floor area of 375 m^2 and a volume of 2,250 m^2.
  - Exterior dimensions are a ground area of 800 m^2 and a height of 7.2 m.
  - The structure is relatively light, with a dead load of 7.5 kg/m^2 .
  - All inflated components can be folded to fit into a 40 ft long shipping container with an overall weight of 6 tons.

Festo



Exhibition Hall Structure

Airbeam-Supported Types

The Exhibition Hall Structure applies advanced pneumatic textile technologies.

- Seventy-two thousand threads/ m^2 hold double-layer walls in place:
  - Slits between wall components are filled with transparent cushions made of Hostaflon ET to create window sections that can be easily replaced by means of side locks.
  - A new type of translucent ethylene-vinyl acetate coating provides light penetration through the pneumatic fabrics.
  - Two textile supply ducts suspended from the ceiling distribute air throughout the building

Festo

Exhibition Hall Structure

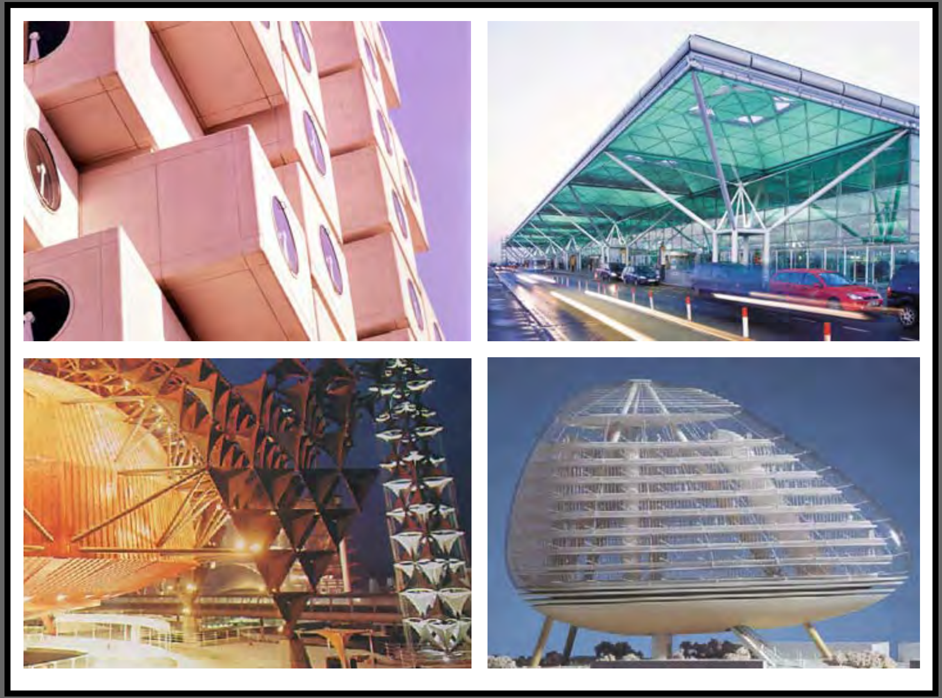
Airbeam-Supported Types

Festo

Exhibition Hall Structure

Airbeam-Supported Types

Go to the list of contents

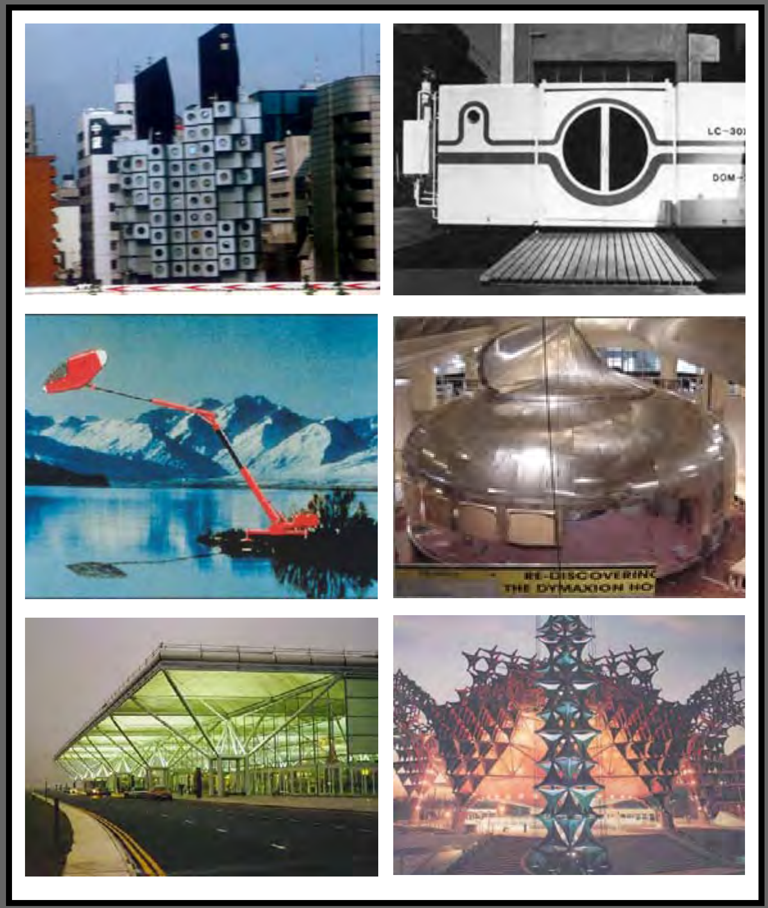


SECTION F : SPECIAL STRUCTURES

SPECIAL STRUCTURES

Some structures are special because they combine features of other types. Others are unique because of the special ways they support loads and transfer stresses. And some are variations that supply to special large scale and long span uses that expand the concept of "shelter" to mega structures. Representative examples of these special cases include:

- Modular complexes:
  - Vertical schemes
  - Horizontal schemes
- Suspended construction:
  - Horizontal types
  - Vertical types
- Space frames:
  - Flat enclosures
  - Curved enclosures



SPECIAL STRUCTURES

MODULAR , SUSPENDED AND SPACE FRAME SYSTEMS

Kisho Kurokawa JAPAN ARCHITECT

The Nakagin Capsule Tower built in the Tokyo Ginza area (1972) was designed to provide single bedroom dwellings, hotel rooms, small office spaces and artist studios in the heart of the city.

- Each of the 144 capsules that comprise the total complex is constructed as a lightweight all-welded steel-truss box covered with galvenized rib-reinforced steel panels with glossy spray paint coatings.
  - External panel parts were covered with a 30 mm coat of spray asbestos fireproofing insulation.
  - Capsule sizes were limited to a maximum 2.5m x 4m x 2.5m high due to limited factory production space.

Nakagin Capsule Tower

Vertical Schemes

The 144 capsules were attached at the rate of five to eight per day, and all work was completed in thirty days.

Kisho Kurokawa **JAPAN ARCHITECT**

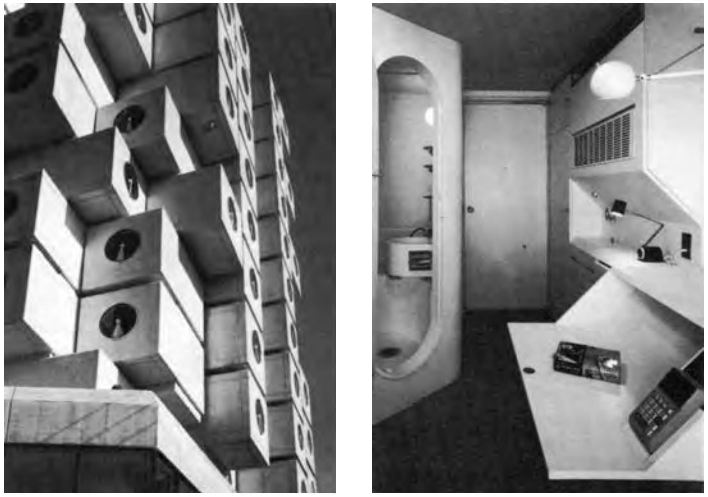
Capsule Installation

Nakagin Capsule Tower

Vertical Schemes

All capsules were constructed of the same standard parts:

- Utilities, interior fittings and even the television sets were assembled and installed at the factory before capsules were attached to the structure.



Capsule Unit

Kisho Kurokawa **JAPAN ARCHITECT**

Nakagin Capsule Tower

Vertical Schemes

Kisho Kurokawa

Nakagin Capsule Tower: Capsule Unit Interiors

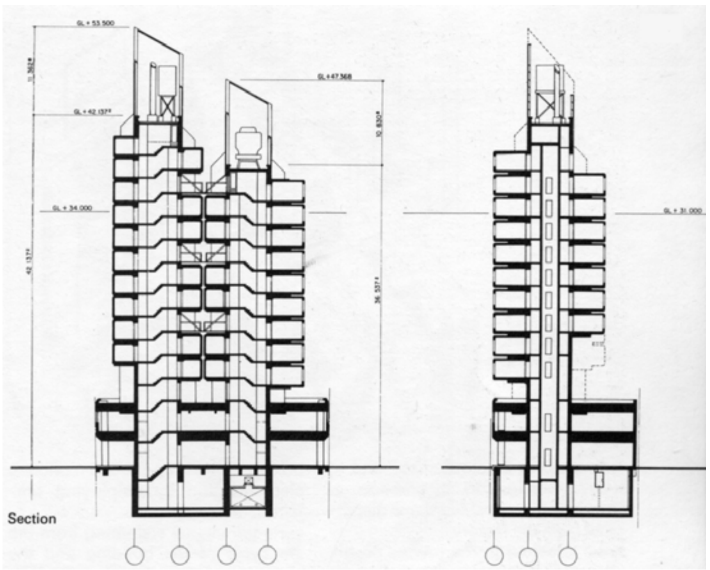
Vertical Schemes

SPECIAL STRUCTURES

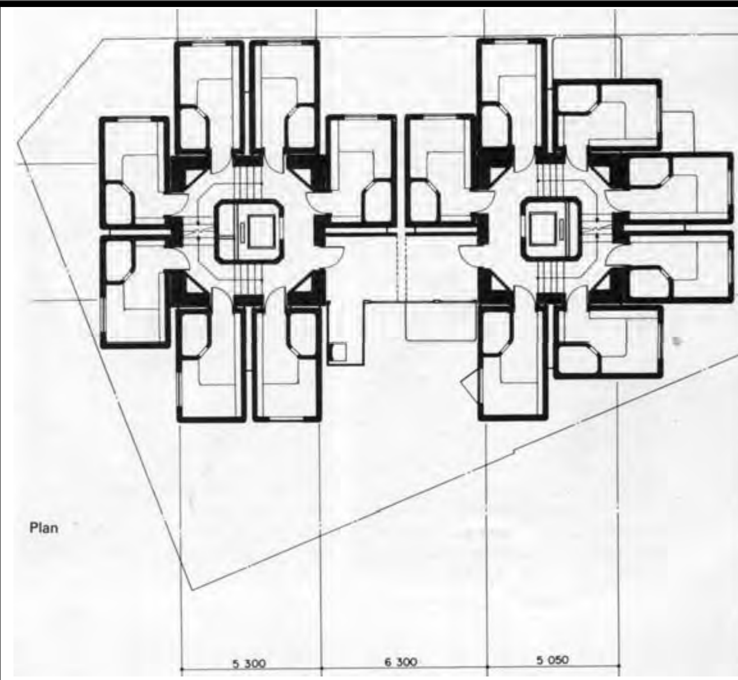
MODULAR COMPLEXES

Kisho Kurokawa

JAPAN ARCHITECT



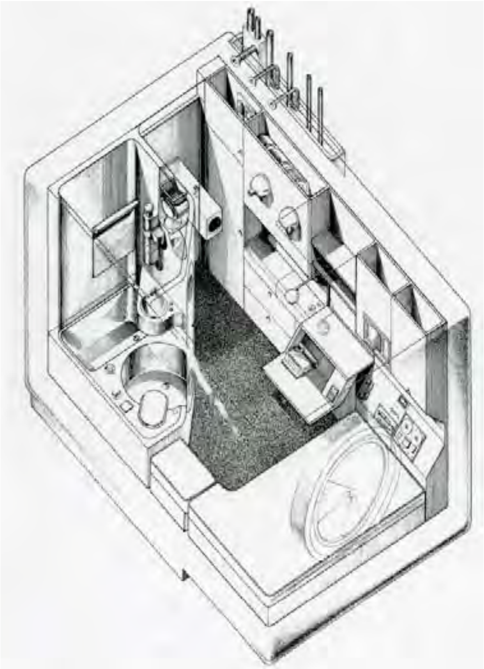
Sections



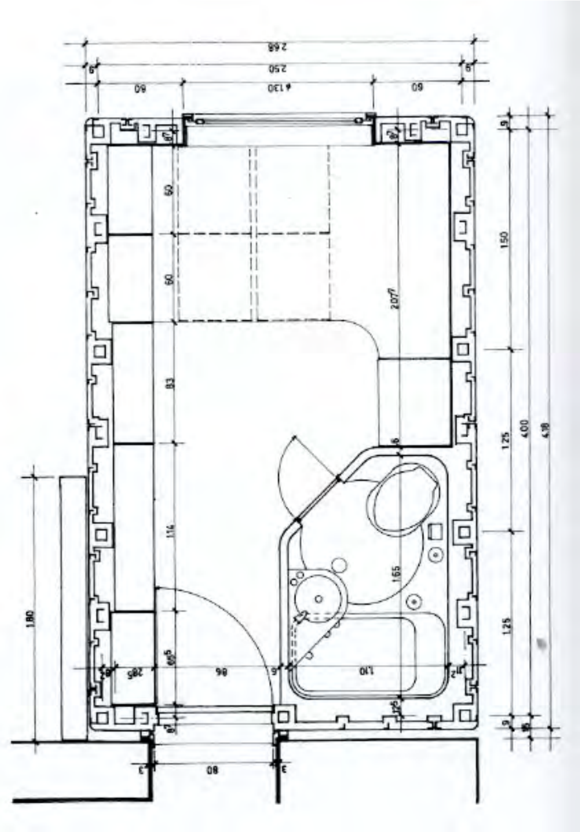
Nakagin Capsule Tower

Vertical Schemes

Kisho Kurokawa **JAPAN ARCHITECT**



Capsule Unit



Nakagin Capsule Tower

Vertical Schemes

Kisho Kurokawa **JAPAN ARCHITECT**

Capsule House K was built in the Japan Nagano Prefecture (1973) as a private home for the architect.

- The home was constructed by attaching modular capsules around a central core set into a steep hill slope:
  - The attached capsules are similar in size to those used for the Nakagin Capsule Tower.
  - Capsules are fabricated form lightweight steel truss-frames and are covered with maintenance-free corten steel panels.
  - The central core is constructed of reinforced concrete.

Capsule House K

Vertical Schemes

Kisho Kurokawa JAPAN ARCHITECT

Capsule House K

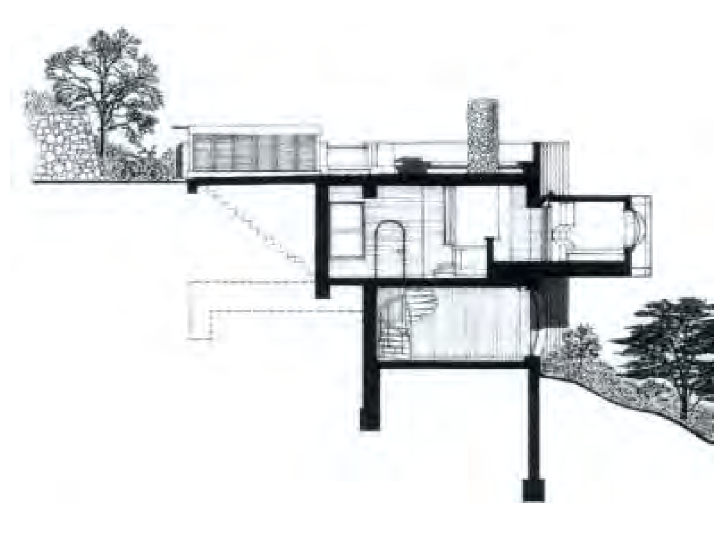
Vertical Schemes

SPECIAL STRUCTURES

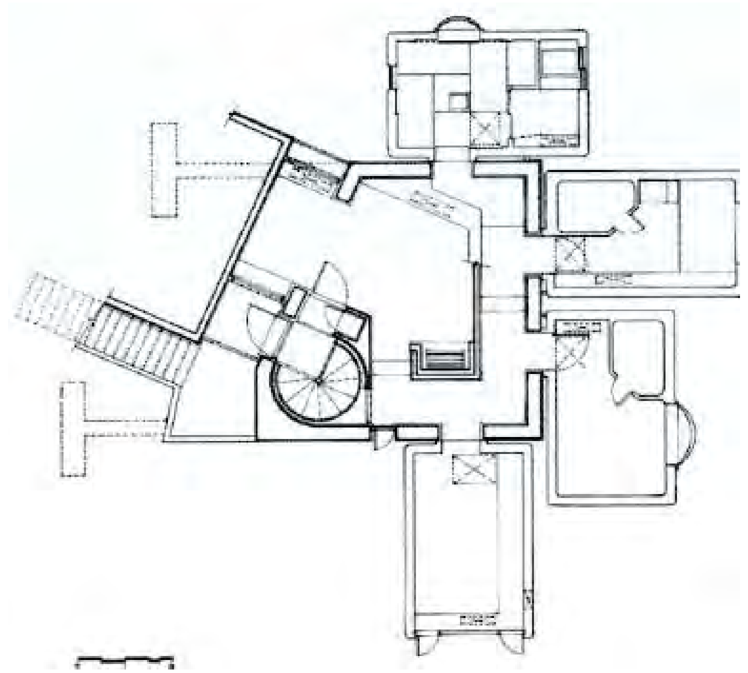
MODULAR COMPLEXES

Each capsule was provided with different interior functions and facilities, including a bedroom, a kitchen, and a tea ceremony room.

Kisho Kurokawa **JAPAN ARCHITECT**



Section Through Site



Capsule House K

Vertical Schemes

Kisho Kurokawa

JAPAN ARCHITECT

Capsule Interior

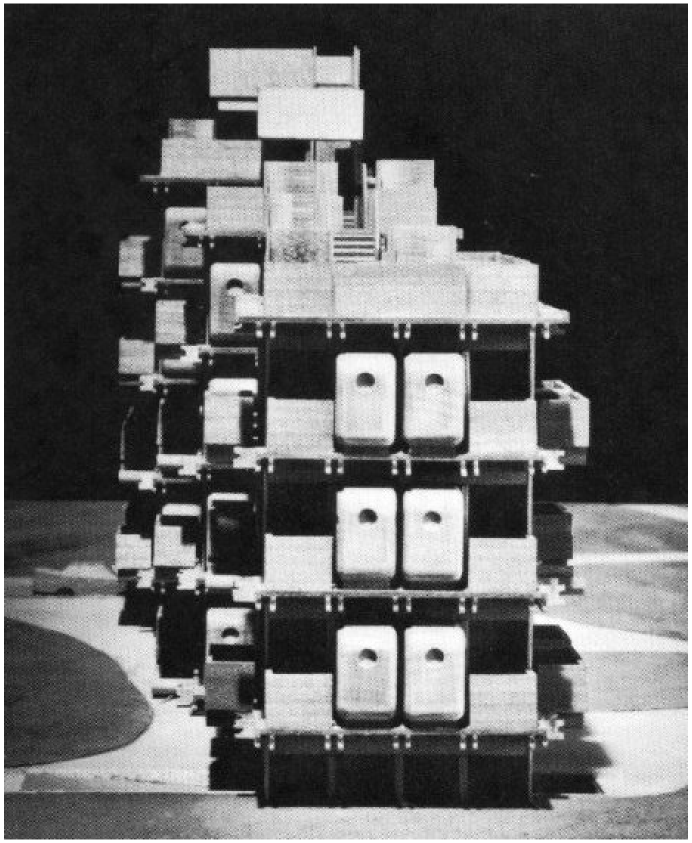
Capsule House K

Vertical Schemes

A Prefabricated Apartment House was proposed in Japan (1962) to be comprised of reinforced concrete units that can be interchanged to accommodate evolutionary requirements or replaced when they lose functionality.

- The plan was intended to combine construction cost and quality control advantages of mass production methods with opportunities for flexibility and versatility afforded by selection of individual units:
  - Each unit would be directly accessible via an open staircase that attaches to the supporting concrete "shelf structure".
  - Individual living units are box-shaped elements that can be organized to meet user requirements.

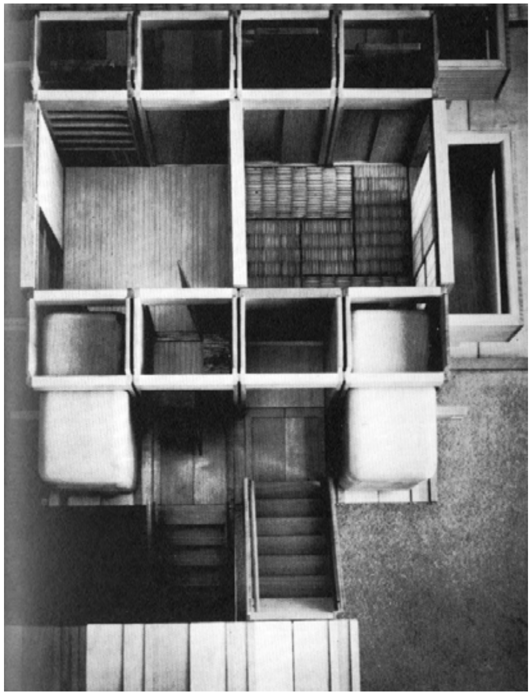
Kisho Kurokawa **JAPAN ARCHITECT**



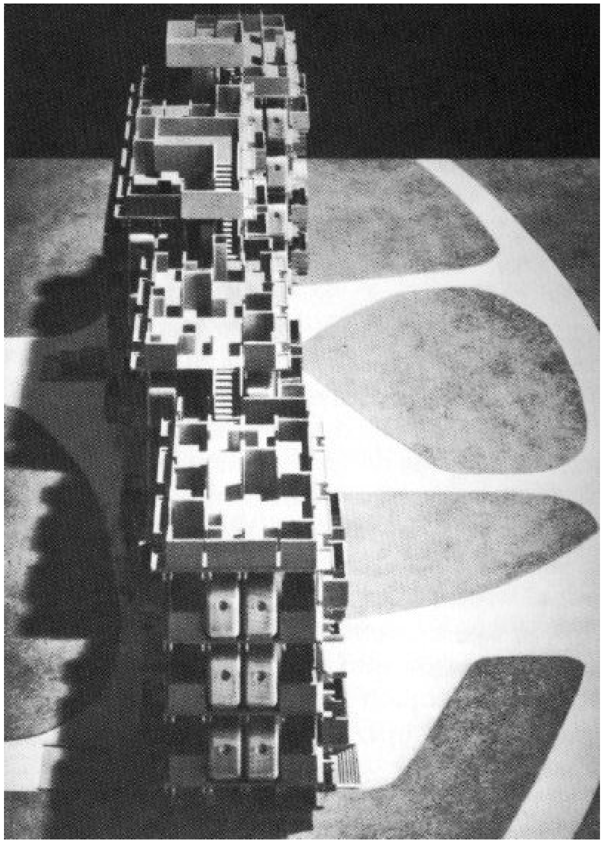
Prefabricated Apartment House

Vertical Schemes

Kisho Kurokawa JAPAN ARCHITECT



Detail of Structure



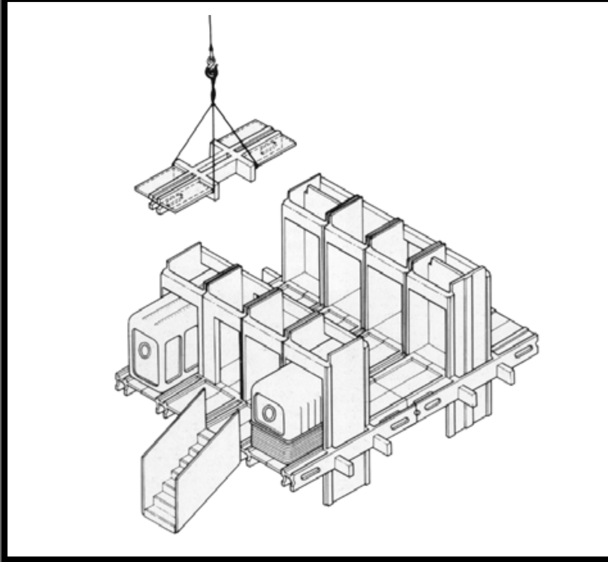
Prefabricated Apartment House

Vertical Schemes

Kisho Kurokawa JAPAN ARCHITECT

Kurokawa emphasized that standardization of sizes and production in quantity should not compromise aesthetic quality or variety.

- Prefabricated approaches can respond to functional variability and provide solutions to needs and conditions that change over time.



Prefabricated Apartment House

Vertical Schemes

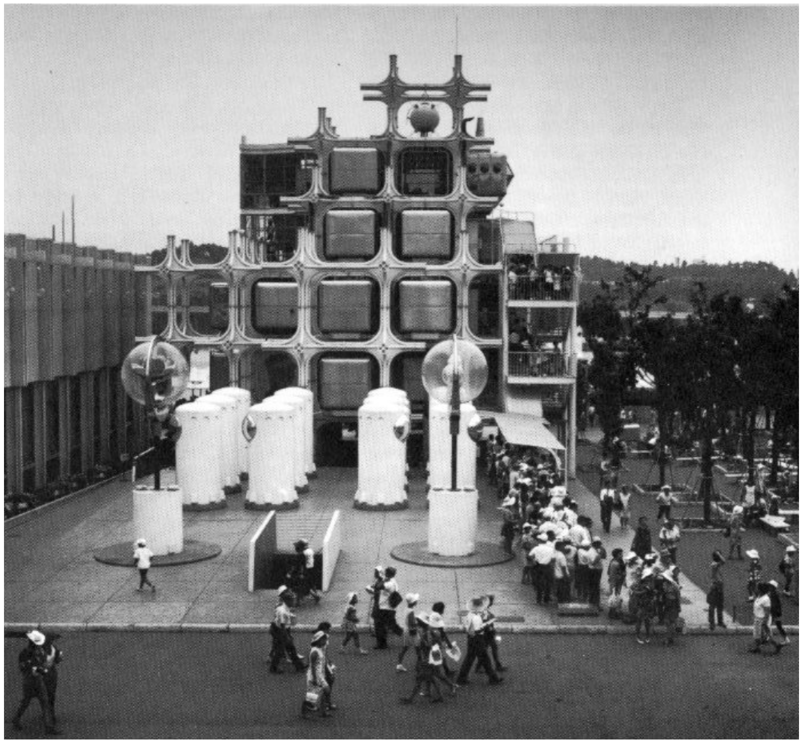
Named after the Takara Group of four large furniture companies, this building at the Osaka, Japan Expo '70 site serves as a classic example of the "Metabolism" movement reflecting Japanese Buddhist aesthetics.

- Capsules for exhibition use and panels for image displays were placed at the interstices of a three-dimensional grid structure.

  - The structure was made by welding steel plates to twelve steel pipes bent into 90o angles to create interlocking skeletal units:

  - Frame units were joined using high-tension bolts, enabling assembly that required only a few days.

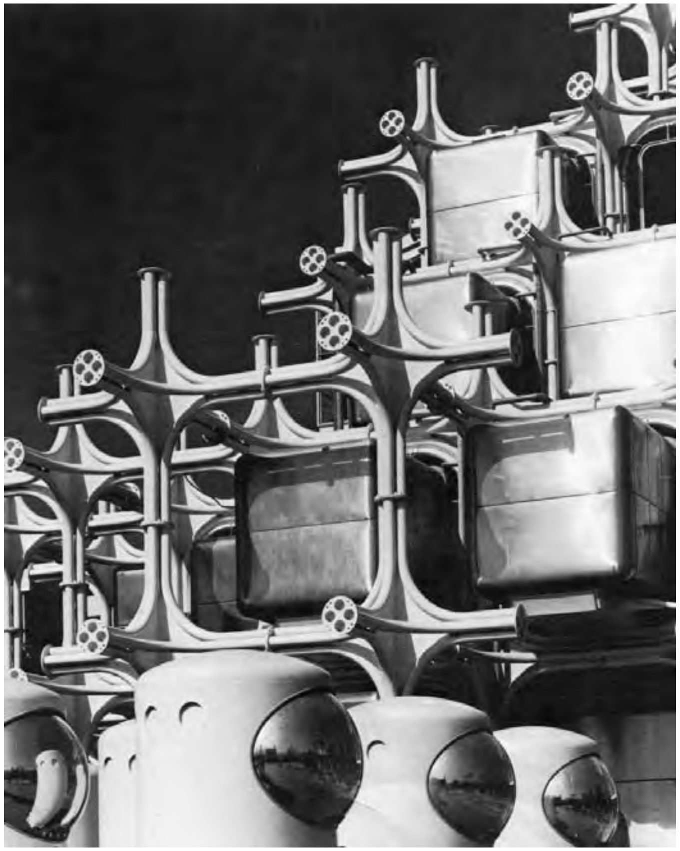
Kisho Kurokawa **JAPAN ARCHITECT**



Takara Beautillion, Expo '70

Vertical Schemes

Kisho Kurokawa JAPAN ARCHITECT



Takara Beautillion, Expo ‘70

A total of 200 prefabricated framing units were used to complete the skeletal structure.

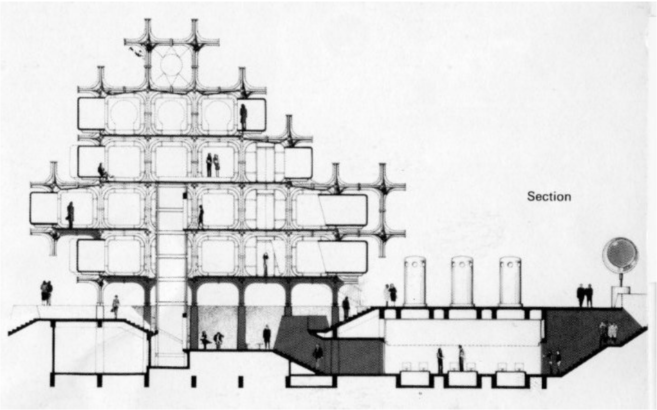
- The end of each “arm” was welded to a circular disc much like a hand with pre-drilled holes for bolts:

- When bolted together they created a space frame of repetitive cubes.
- Precast concrete floor slabs dropped into the cubes like a toy construction kit.
- Thirty stainless steel boxes were placed in the steel frame to contain exhibit elements.
- The structure required two external stairs to accommodate viewer access.

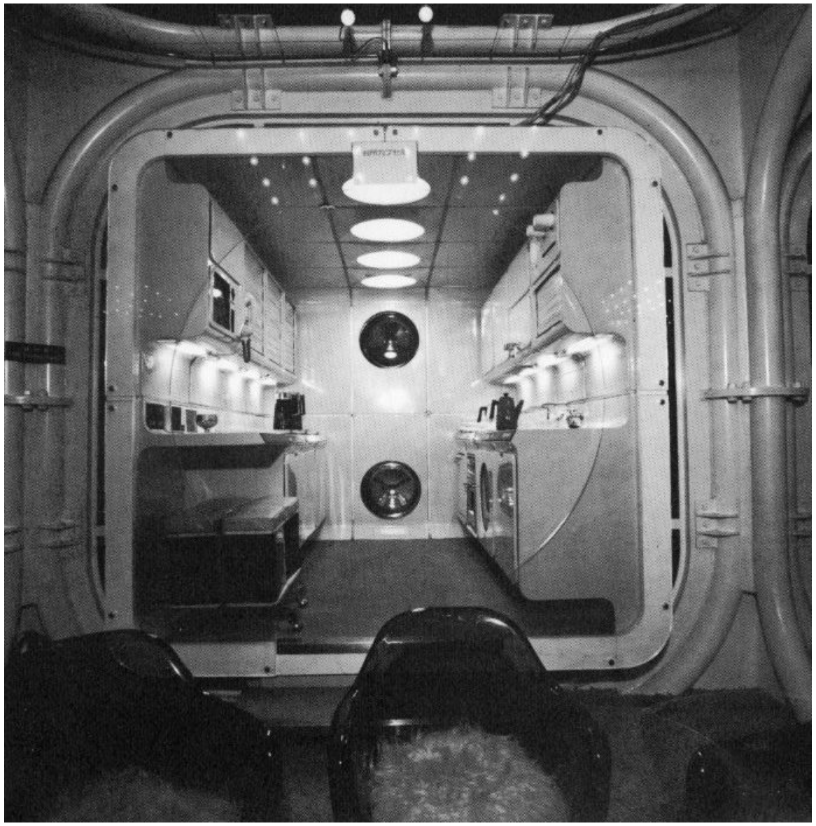
Vertical Schemes

Kisho Kurokawa

JAPAN ARCHITECT



Section View



Takara Beautillion, Expo ‘70

Vertical Schemes

Kisho Kurokawa **JAPAN ARCHITECT**

Site Construction

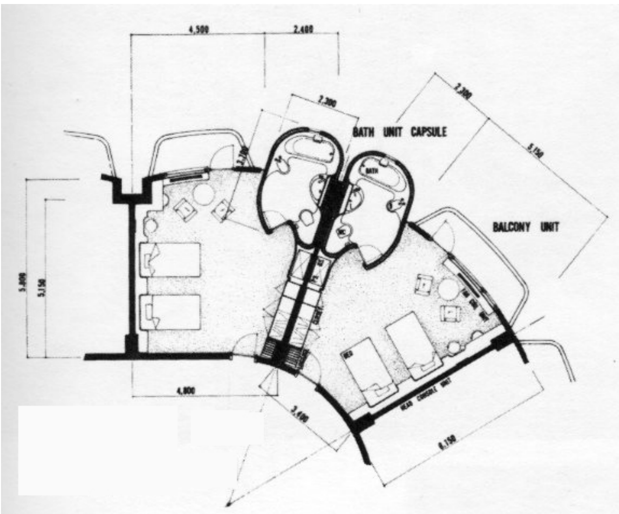
Takara Beautillion, Expo '70

Vertical Schemes

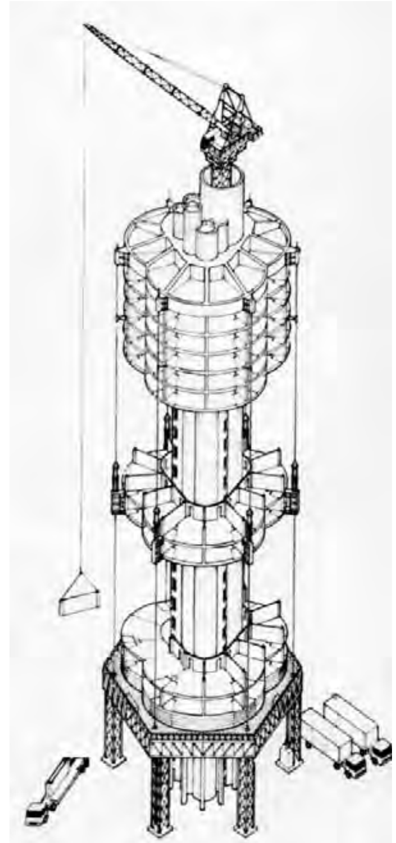
The proposed project would incorporate an international conference hall, casino, hotel, shopping center and sports area into a vertical structure complex.

- The high-rise portion of the hotel would be erected by a build-up method, and bath units would be capsules attached on the outside for ease of assembly and removal.

Kisho Kurokawa **JAPAN ARCHITECT**



Site Construction

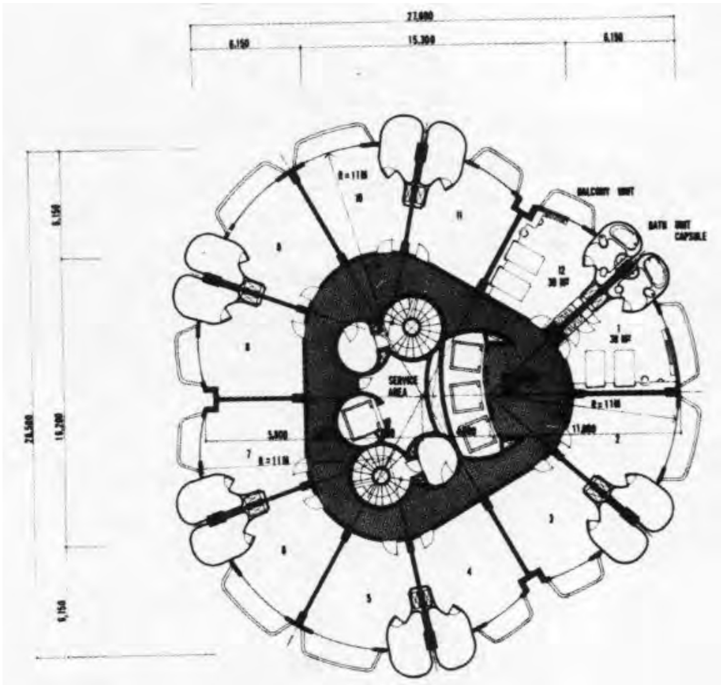


Um Al-Kanhazeer Project

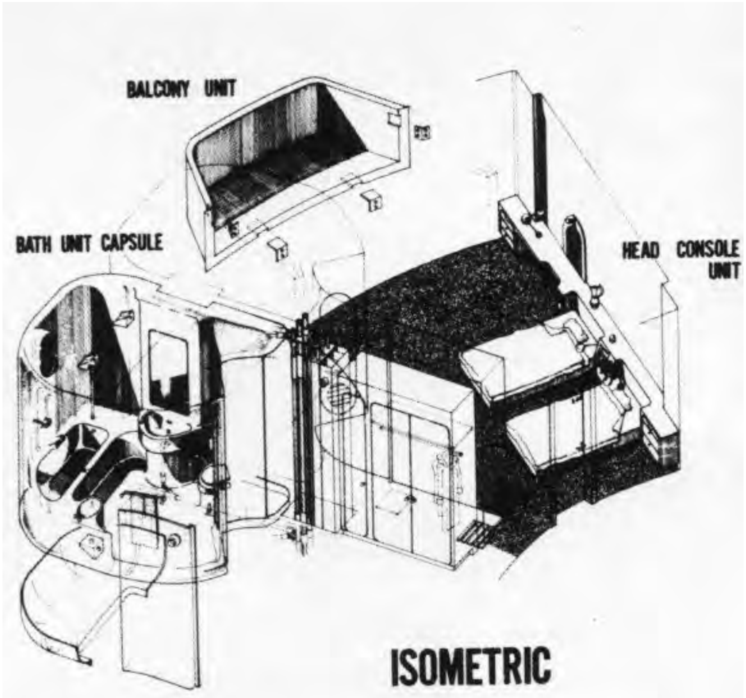
Vertical Schemes

Kisho Kurokawa

JAPAN ARCHITECT



Typical Floor Level Plan



Um Al-Kanhazeer Project

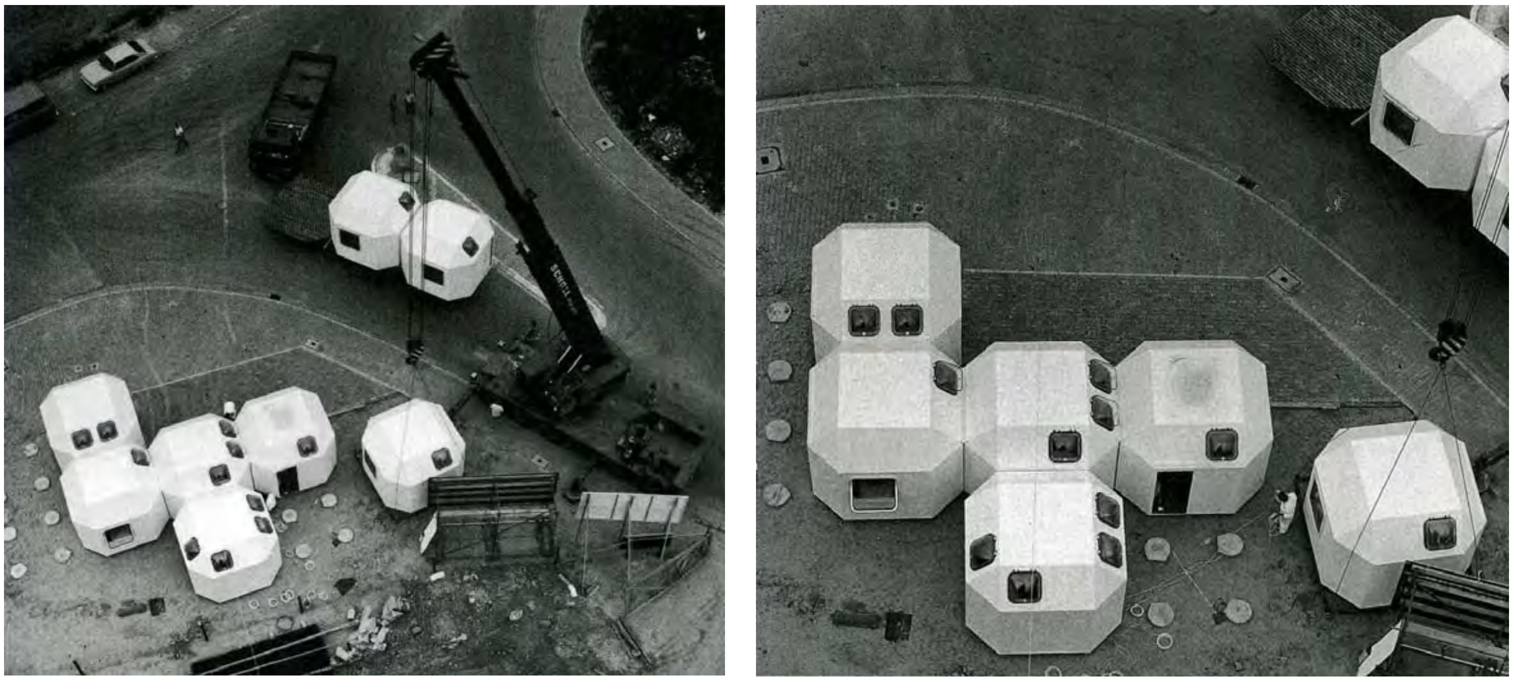
Vertical Schemes

SPECIAL STRUCTURES

MODULAR COMPLEXES

Produktbau Huster and Hubner

Living in Motion



Casanova 2400, Variously Configurable Models, 1975

Horizontal Schemes

SPECIAL STRUCTURES

MODULAR COMPLEXES

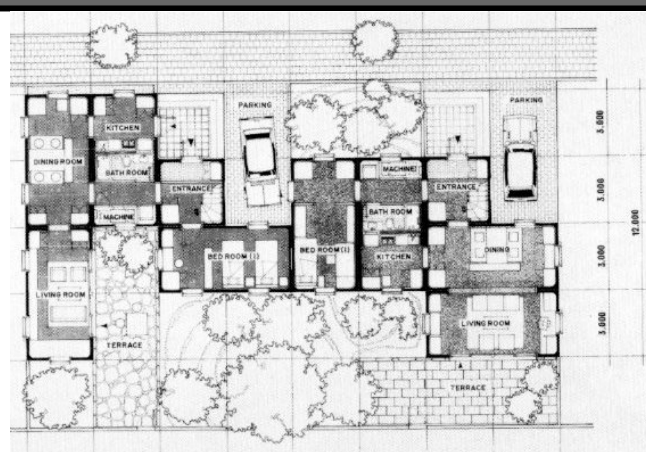
Concrete House unit prototypes were developed in 1975 as an experiment aimed at creating a townhouse neighborhood.

- Several 3m x 6m units were quickly manufactured using a special concrete forming process:

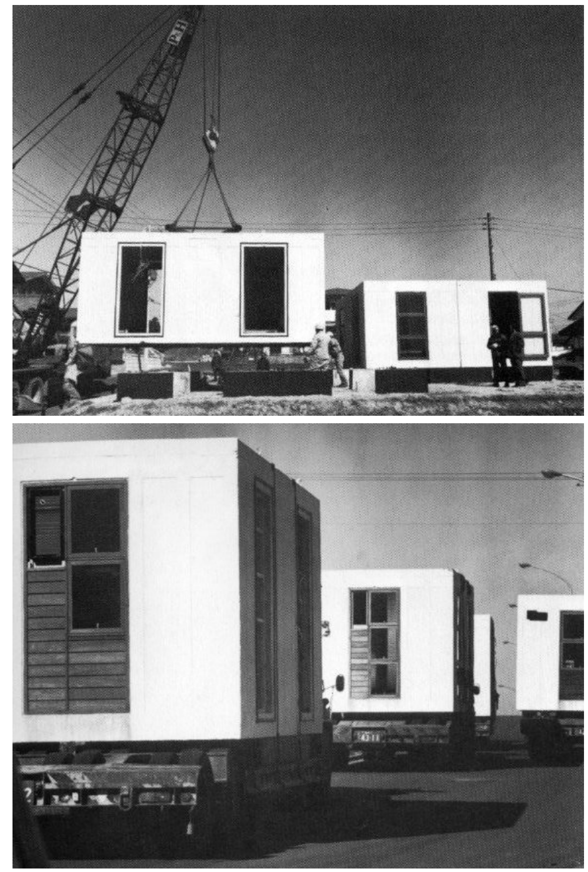
- Units were transported on carriers, and then bolted together at the site.

- The buildings could be extended up to three stories in height as well as connected together to form multi-dwellings.

Kisho Kurokawa **JAPAN ARCHITECT**



Site Plan

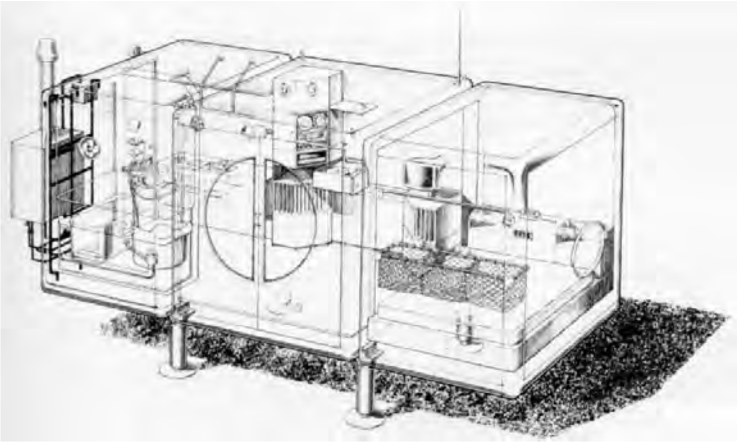


Concrete Capsule House

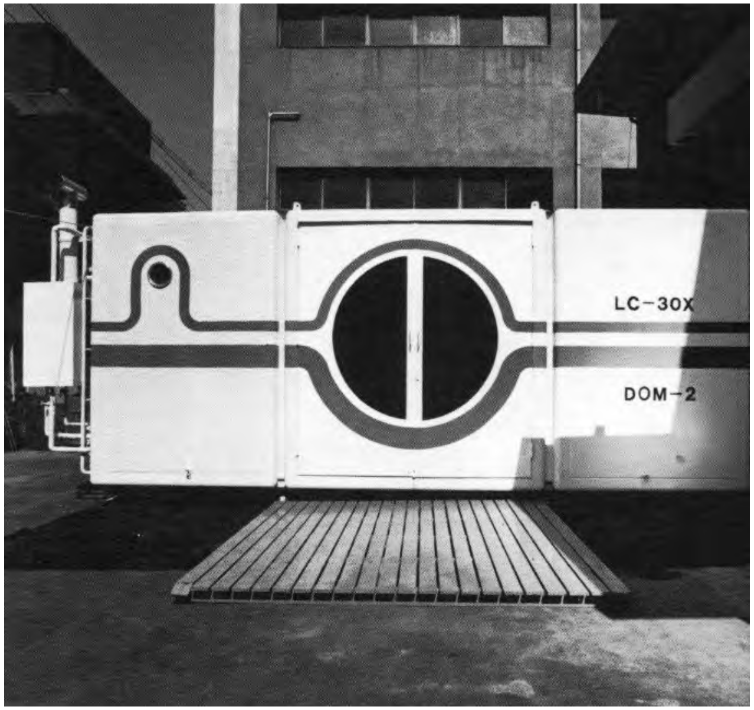
Horizontal Schemes

Kisho Kurokawa

JAPAN ARCHITECT



Capsule Unit



Concrete Capsule House

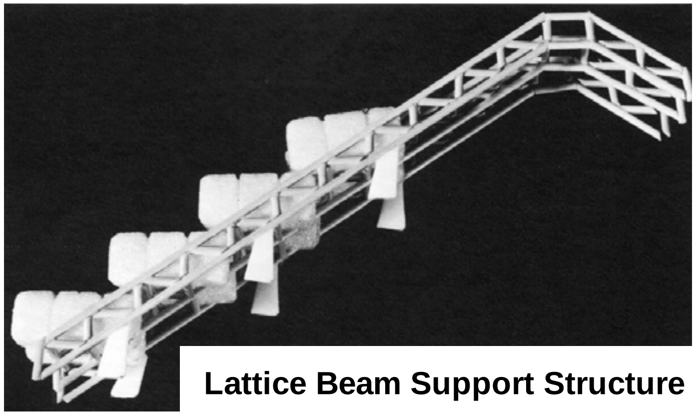
Horizontal Schemes

SPECIAL STRUCTURES

MODULAR COMPLEXES

Kisho Kirokawa proposed a bridge support structure to elevate module capsules above the land to minimize disturbance to the natural environment.

- Ducts for power lines, water supply and drainage pipes would attach to an access staircase.
  - The attached 3m x 6m capsules would be larger than those used for the Nakagin Capsule Tower.



Lattice Beam Support Structure

Kisho Kurokawa

JAPAN ARCHITECT

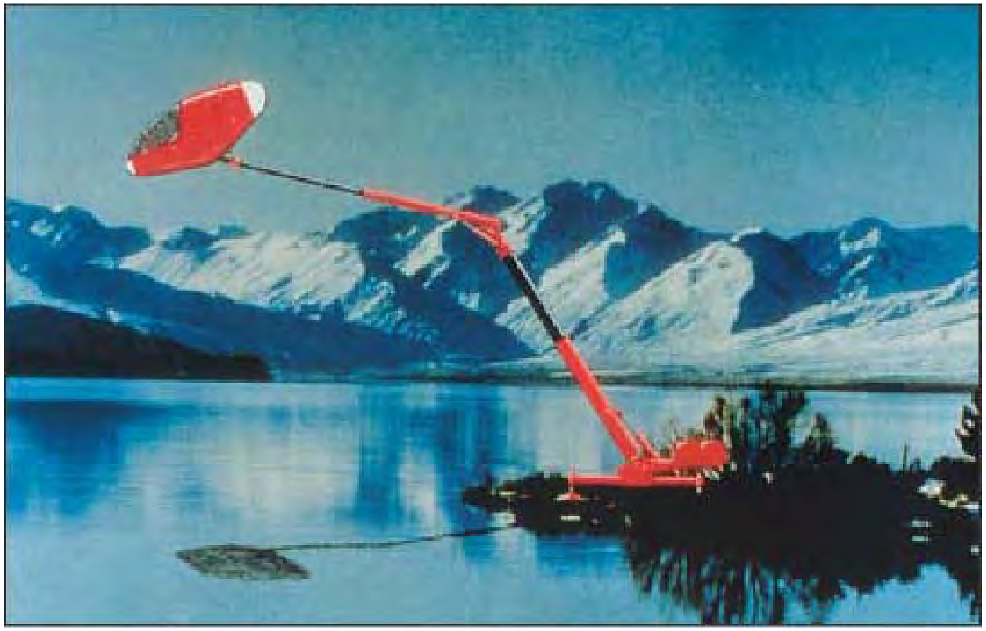
Capsule Village

Horizontal Schemes

This proposal for a kinetic living unit would suspend a two-person pod on an articulating crane arm to provide a variety of interior views.

- The “Peanut” habitat would move according to the mood of the users throughout the course of daily interests and activities.
  - The design would utilize a standard hydraulic crane arm that could be controlled from inside the capsule.
  - The entire assembly could be moved to different sites by conventional transit carriers.

Jan Kaplicky/ David Nixon **FUTURE SYSTEMS**

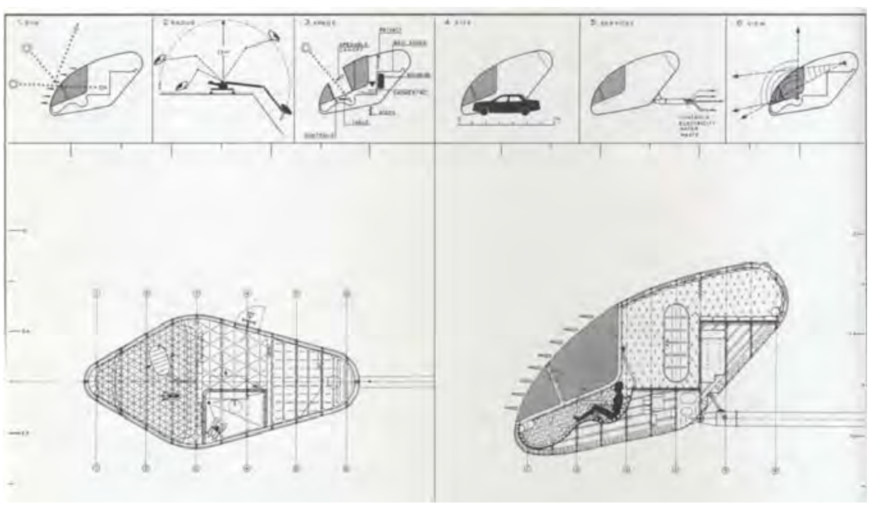


The Peanut

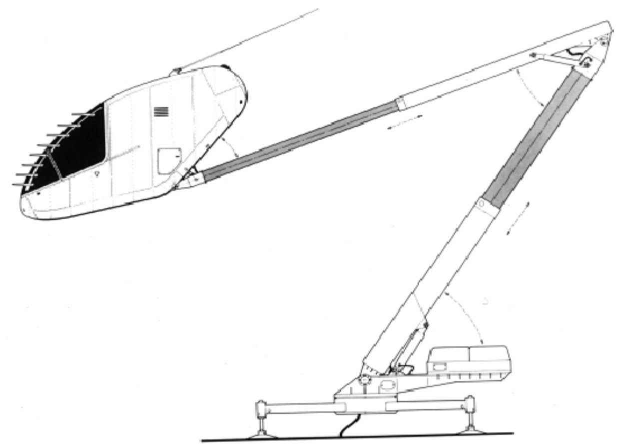
Horizontal Types

Jan Kaplicky/ David Nixon

FUTURE SYSTEMS



Pod Articulation and Features



The Peanut

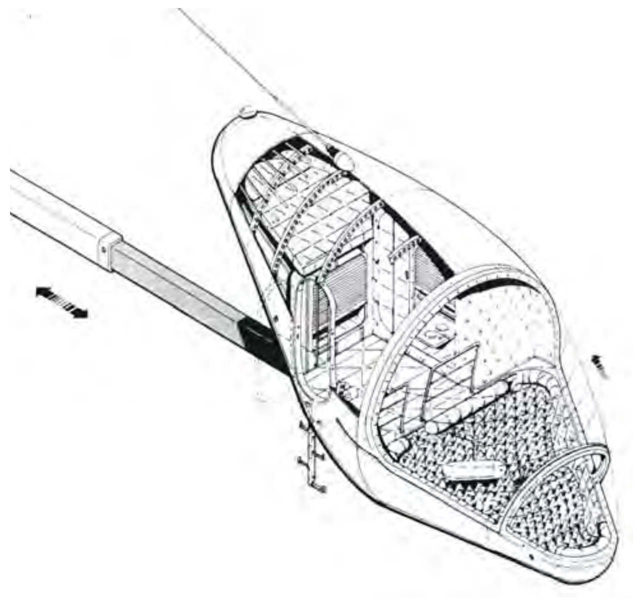
Horizontal Types

SPECIAL STRUCTURES

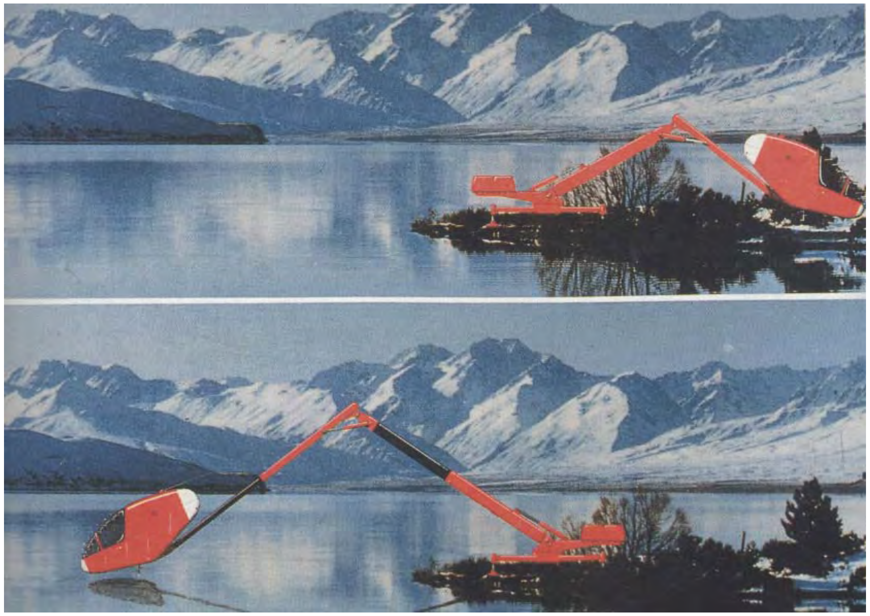
SUSPENDED CONSTRUCTIONS

Jan Kaplicky/ David Nixon

FUTURE SYSTEMS



Pod Interior



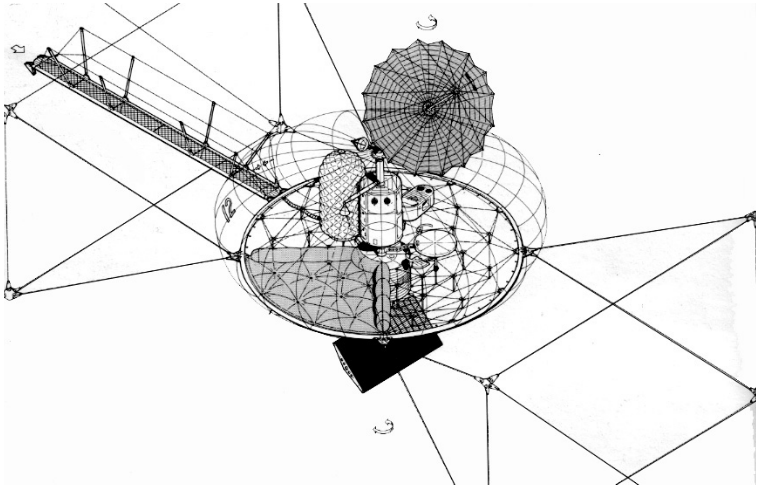
The Peanut

Horizontal Types

SPECIAL STRUCTURES

SUSPENDED CONSTRUCTIONS

Jan Kaplicky/ David Nixon FUTURE SYSTEMS



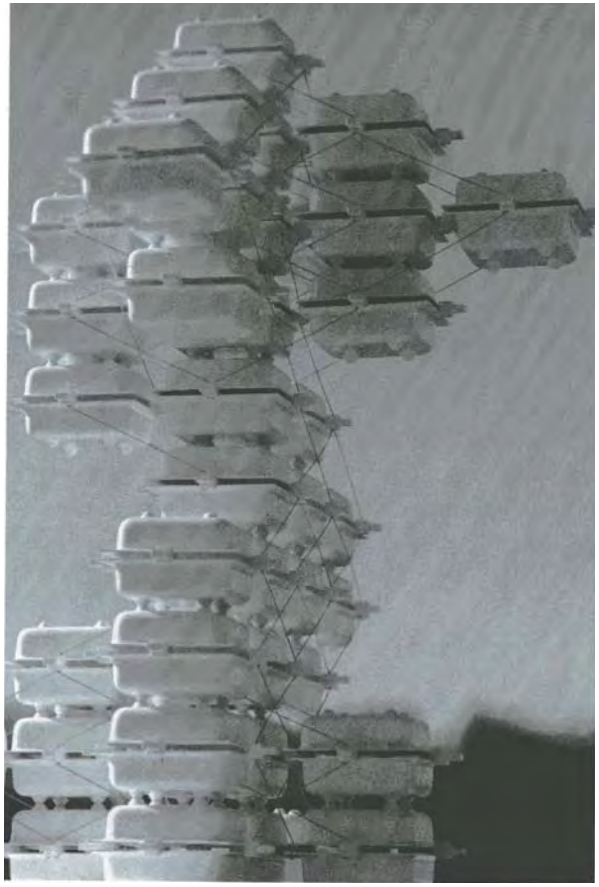
Suspended Inflatable Bubble

This Future Systems concept proposes a suspended inflatable structure as a short-stay accommodation for two people.

- The basic structure would be an air-supported transparent sphere with an aluminized coating on the upper part to reduce solar heat buildup and provide partial shading:

  - The floor element would consist of an aluminum circular frame and a series of vertical compression and horizontal torsion members forming a series of radial trusses.
  - The center contains functional services, storage drums and a telescopic mast containing an adjustable sun shade umbrella.
  - The entire assembly would be suspended by four cables attached to ground anchor points, with access provided by a lightweight bridge.

Wolfgang Dohring **LIVING IN MOTION**



Prefab Living Container, 1968

Wolfgang Dohring proposed a “living container” system made of prefabricated modular cells in 1968 which might be stacked and cantilevered to create a variety of organizational forms.

- Cables attached to frames at the cell horizontal mid-sections would stabilize the structure and its cantilevered modular elements.
  - The same process and forms would be used to mold the modules’ upper and lower halves, to reduce costs and to expedite production.
  - The stacked/ cantilevered units would be balanced along the central vertical axis to avoid overturning due to wind and dead loads.

Horizontal Types

The Dymaxion House, built in 1927, was a hexagonal metal structure which reflected Bucky's efficient, lightweight approach to building construction.

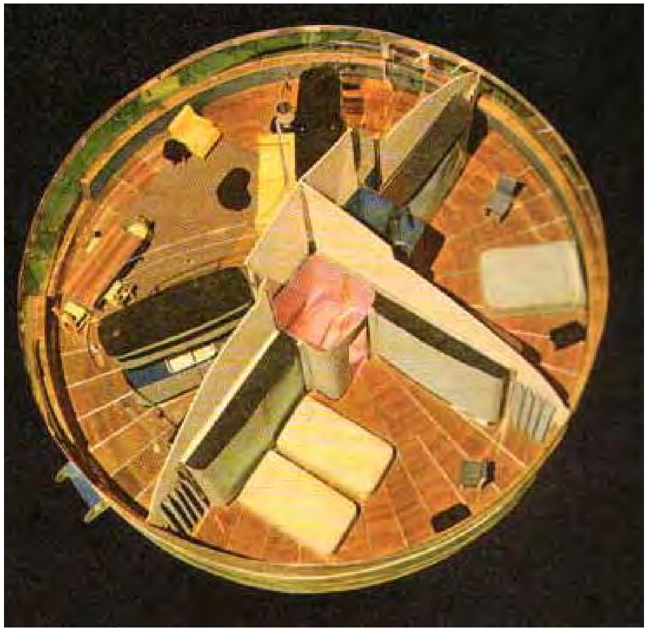
- Fuller's love of compact, space-saving, multi-functional planning is reminiscent of ship cabin layouts, including a washing unit and a cupboard design that utilized a rotating conveyor belt with a large variety of drawers:
  - The living spaces were radially arranged and suspended from a central mast, causing them to seem to float freely in the air.
  - Although the house was planned down to the last detail, it was never built.
  - It was projected to weigh three tons, and was estimated to cost about $3,000.

Buckminster Fuller

Dymaxion House

Vertical Types

Buckminster Fuller



Dymaxion House

Vertical Types

SPECIAL STRUCTURES

SUSPENDED CONSTRUCTIONS

Green Building is a conceptual proposal for an environmentally-responsible office facility.

- The building would rest upon a tripod mega-structure, leaving the ground level open to be used as a garden:

- Each of the hollow steel floor decks would be suspended from the apex of the tripod by ties around their external edges.

- The streamlined form would draw air over the building surface, and wind scoops would direct falling cool air through intakes into the building.

- Stale air would be vented through louvers at the top of the structure, and heat would be recovered during cooler months.

- Most office areas would receive natural lighting, and daylight would be bounced by mirrors off the center of the building and scattered by deflectors.

Future Systems

Green Building, 1990

Vertical Types

The Coexistence Tower was conceived as a series of stacked high-rise elements arranged around and supported by a central structural and service core.

- The basic structure is an externally stiffened tube with an inner cylindrical core in compression, and a cylindrical external truss in tension:
  - The cone-shaped functional habitat elements each provide multiple floors of offices and residential apartments.
  - Floors on the undersides of these elements would be shielded from direct sunlight and present angled panoramic views.
  - The design provides for 150 floors with a total of 76,000 m^2 of residential and 285,000m^2 of office space.

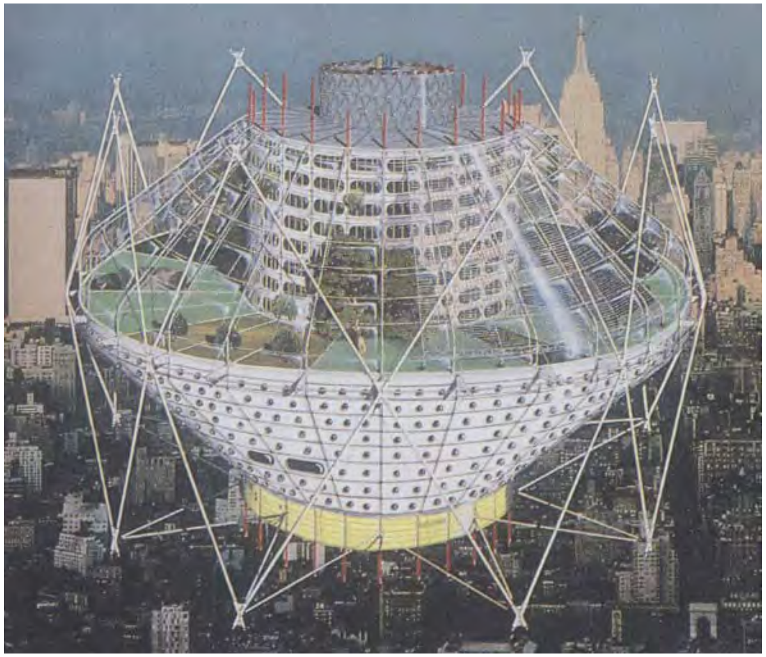
Future Systems **LIVING IN MOTION**

Coexistence Tower

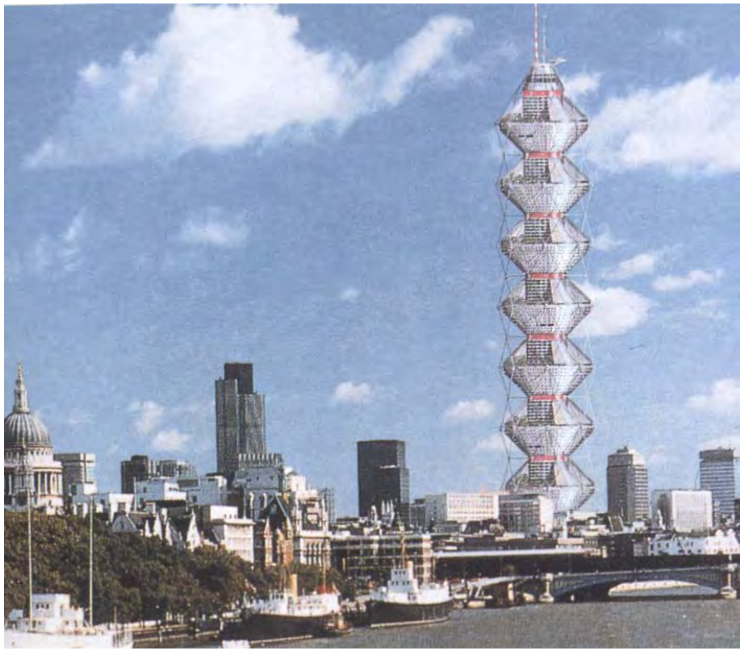
Vertical Types

Future Systems

LIVING IN MOTION



Cone-Shaped Habitat Element



Coexistence Tower

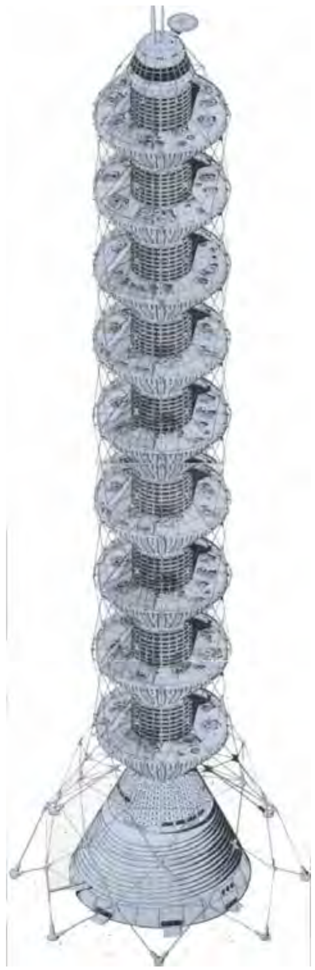
Vertical Types

SPECIAL STRUCTURES

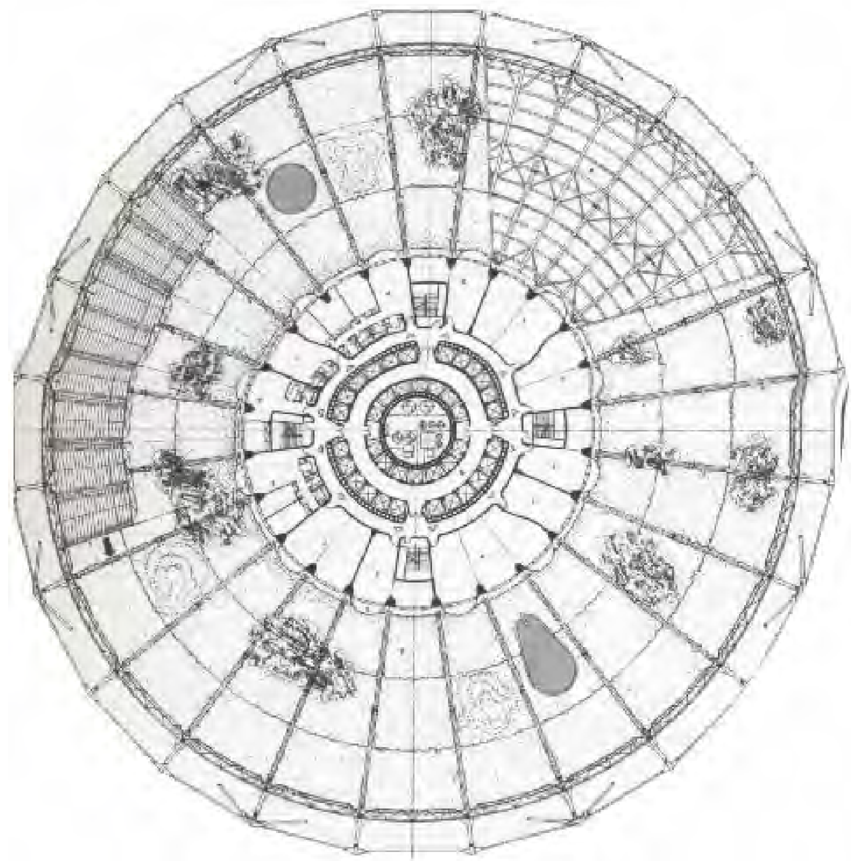
SUSPENDED CONSTRUCTIONS

Future Systems

Central vertical loads would be carried by a cylindrical curved structure, and stacked element perimeters would be lifted and stiffened by a tension truss. The truss cables would originate at the top mast and extend to ground anchors.



Coexistence Tower



Typical Floor Plan

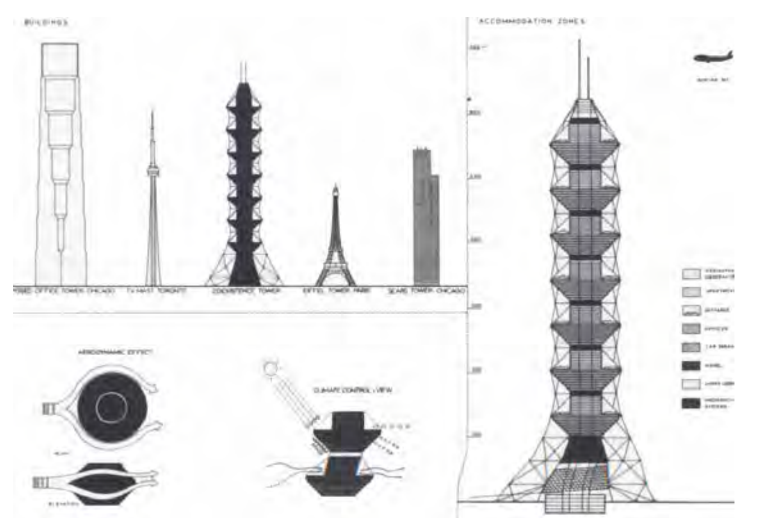
Vertical Types

SPECIAL STRUCTURES

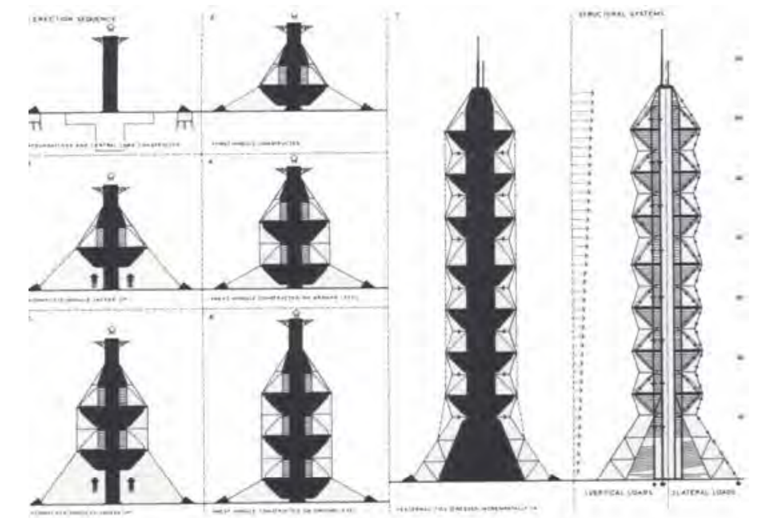
SUSPENDED CONSTRUCTIONS

Future Systems

LIVING IN MOTION



Scale and Structure



Coexistence Tower

Vertical Types

SPECIAL STRUCTURES

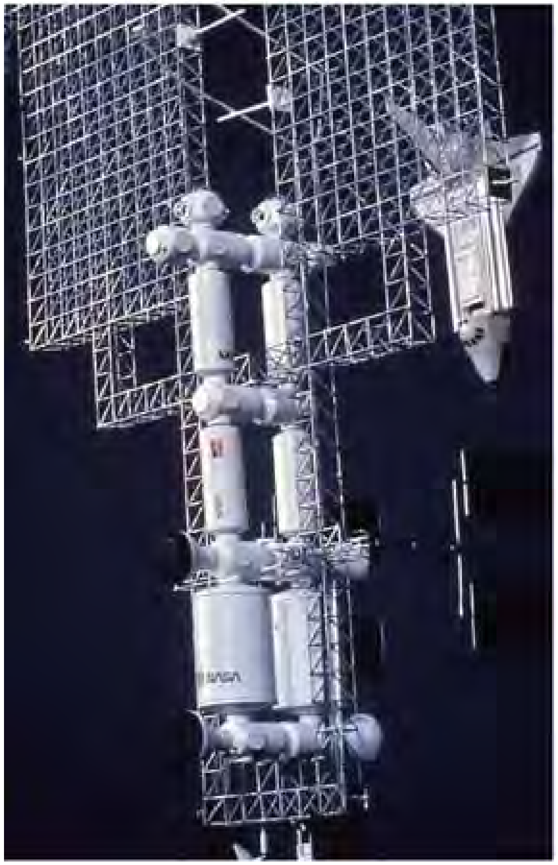
SUSPENDED CONSTRUCTIONS

Space frames are truss structures that span in more than one direction to create decks, roofs and walls.

- To span multi-directionally, the components must connect both horizontally and vertically:

  - Components connect in different configurations to create hexahedral, pentahedral, tetrahedral and octahedral geometries.
  - Connectors include spherical and flat types using welded, bolted, riveted, “plug together” and hinged, folding fasteners.
  - Lightweight compactable construction combined with strength/ rigidity extends space frame benefits literally to space applications.

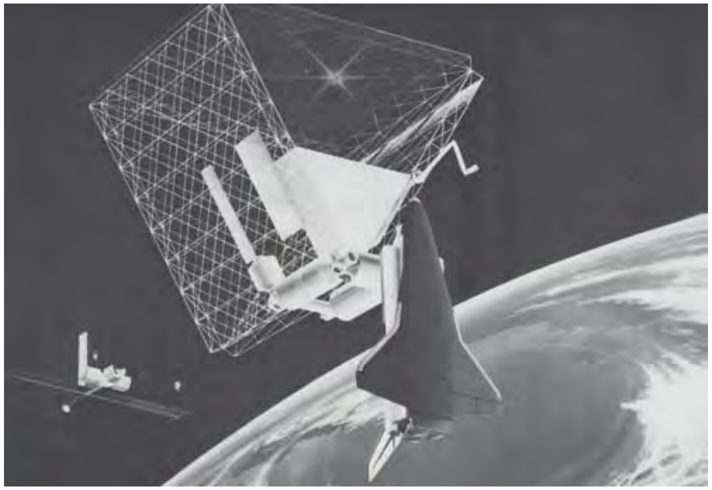
SICSA



SICSA Space Post Concept

Types and Applications

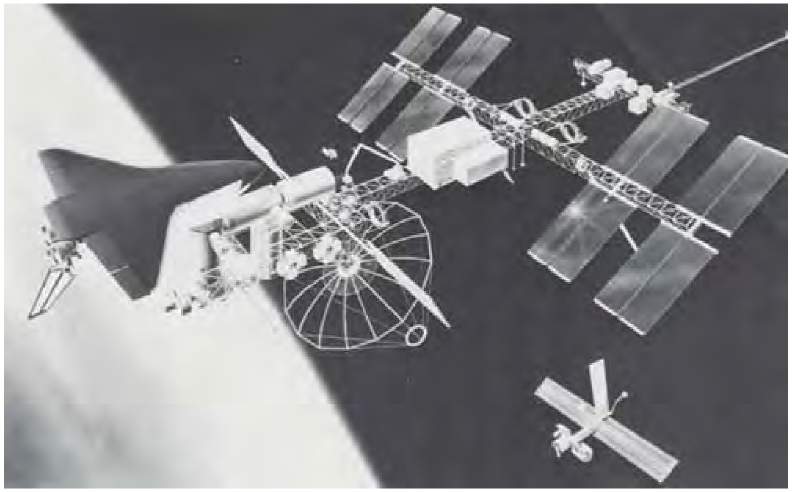
SPACE STATIONS AND PLATFORMS



The Delta configuration was devised to provide stiffness to avoid dynamic controllability problems associated with the long, flexible Power Tower truss.

NASA Delta Space Station Concept

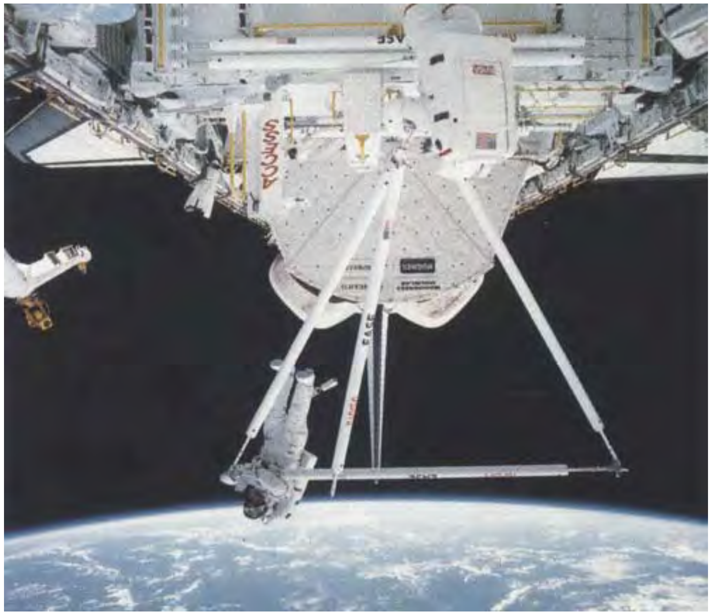
SPACE STATIONS AND PLATFORMS



The Power Tower featured a long box truss backbone structure that could accept a variety of functional attachments, including modules, storage facilities and solar arrays.

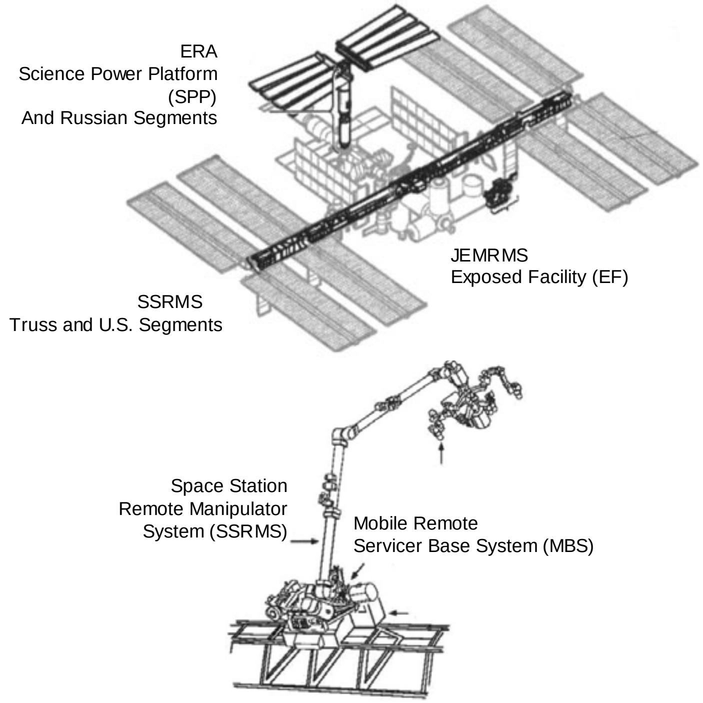
Early NASA Power Tower Concept

NASA



Trusses provide a light weight, strong and versatile structural approach.

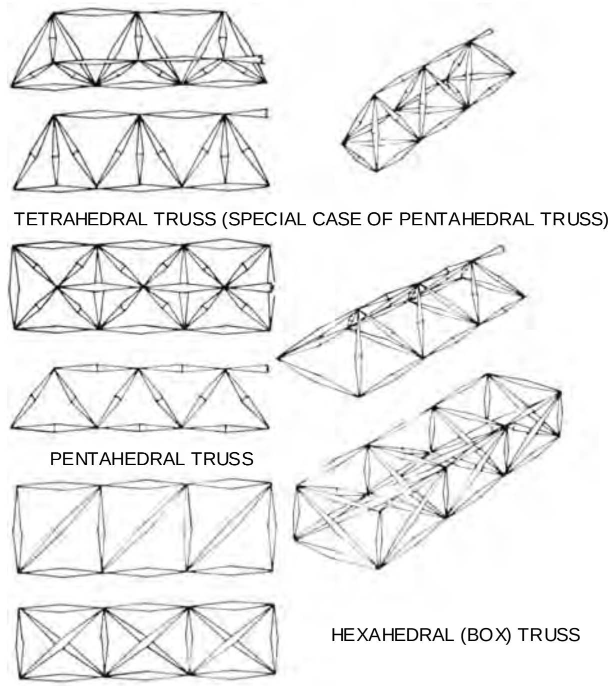
Truss Construction from Orbiter



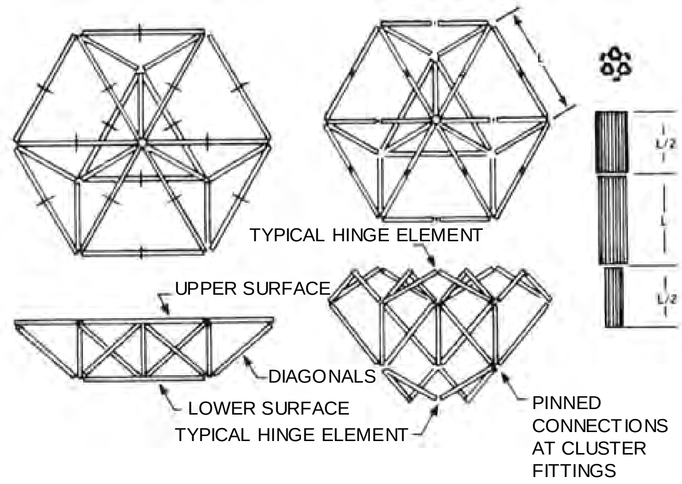
International Space Station

Types and Applications

SPACE STATIONS AND PLATFORMS



Common Truss Geometries

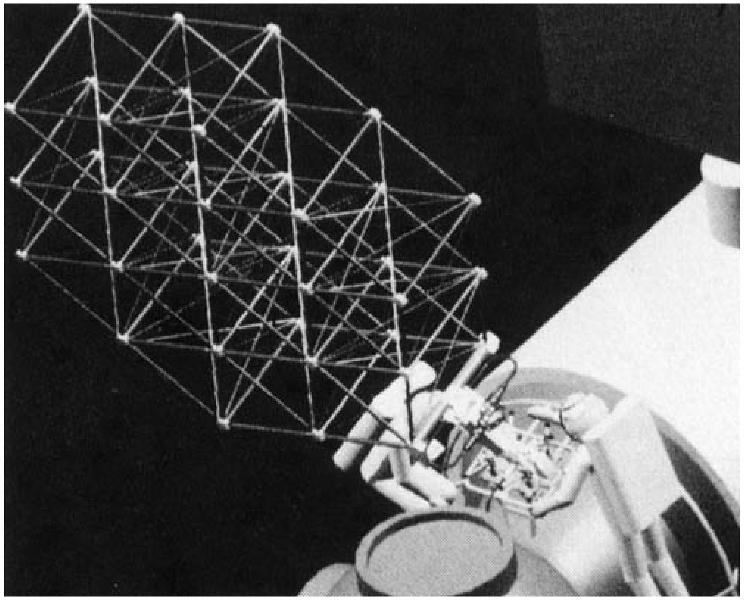


Strictly speaking, there is no such thing as a purely tetrahedral truss since its geometry does not fill in all surface spaces when tetrahedrons are joined together.

"Tetrahedral" Trusses

A “large unfurlable structure” called ERA was developed by Aerospatiale for the French space agency CNES, and was deployed by a French astronaut onboard the Russian Mir space station in late 1988:

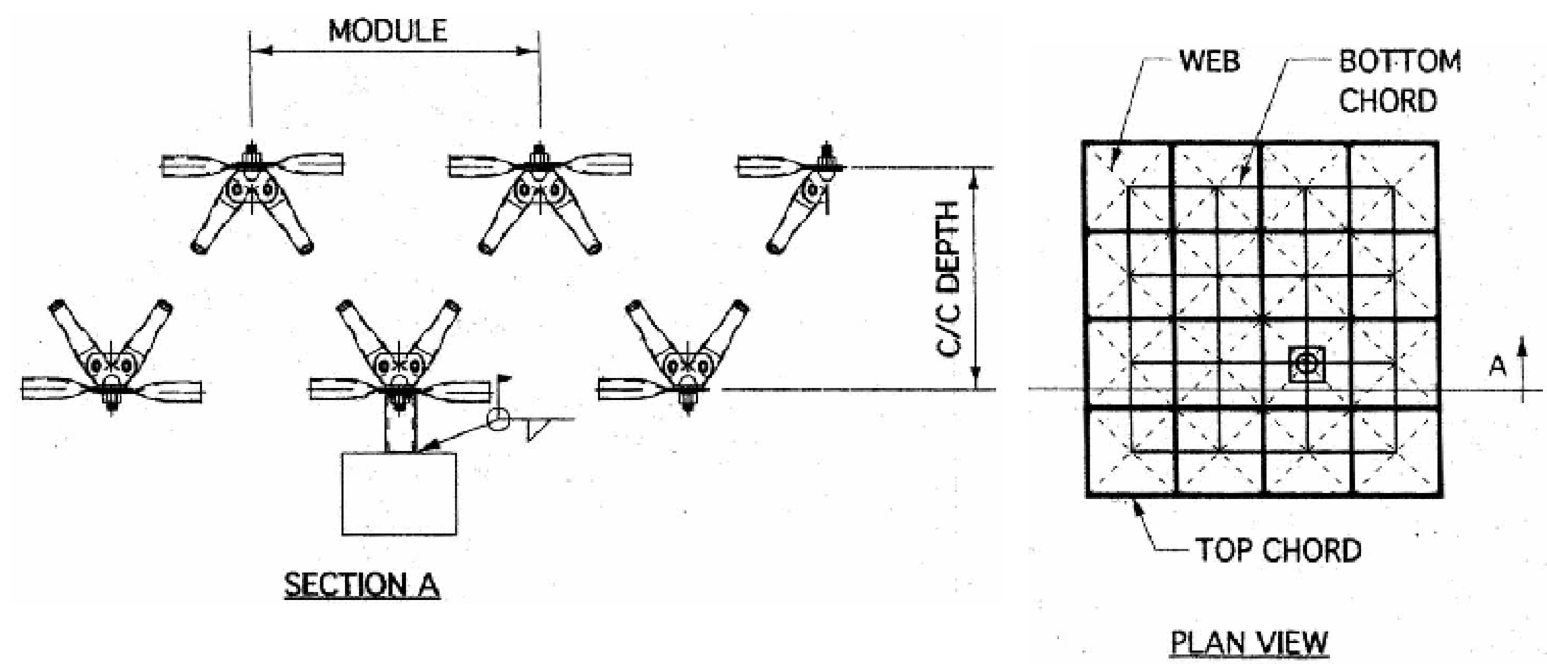
- The 12.5 ft. x 11.8 ft. x 3.3 ft. structure was made up of 1.18 in. diameter carbon fiber tubes linked together by light alloy joints forming 24 prismatic-shaped sections.
- The assembly contained more than 5,000 parts, including more than 1,300 bearings which fit into a 1 ft. diameter, 2 ft. high bundle which deployed in 2.5 seconds.



The system deployed automatically when a restraint cable was cut by a thermal knife.

ERA Unfurlable Structure

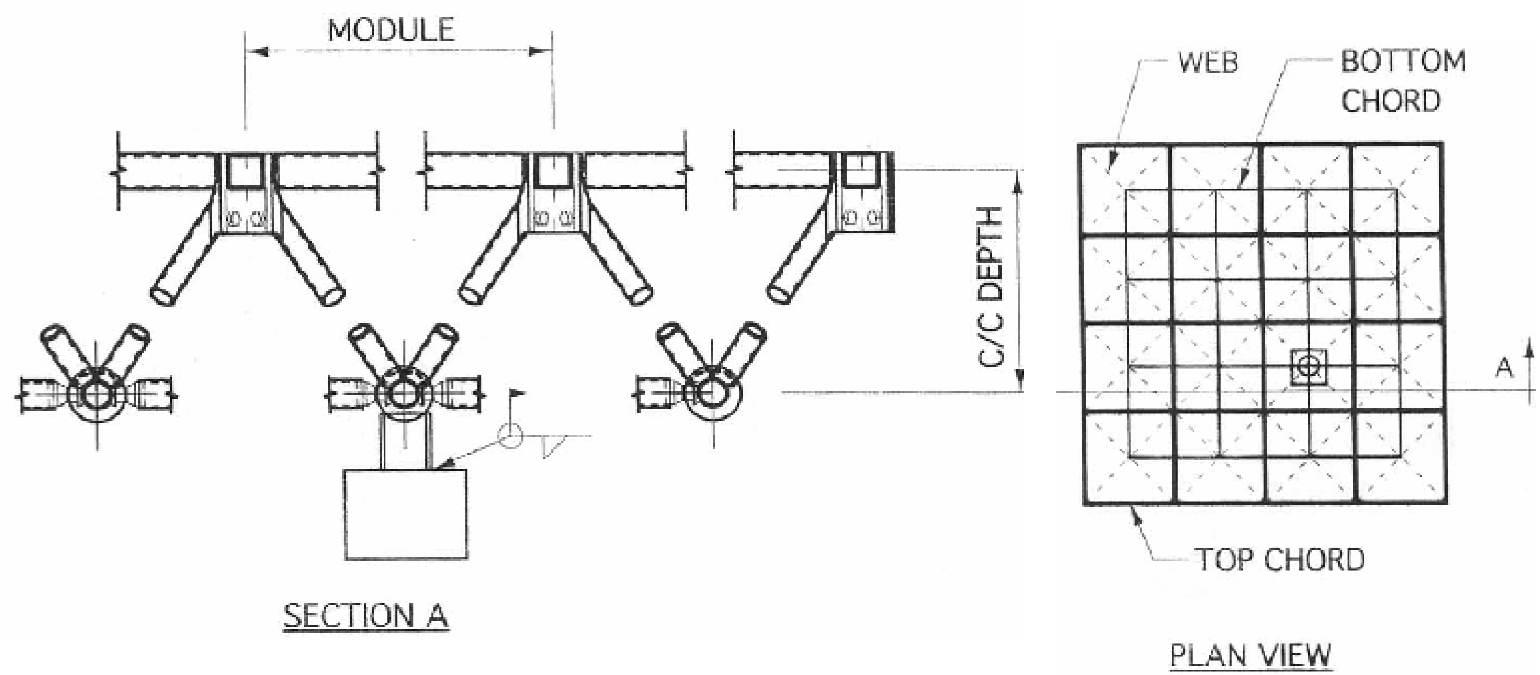
Delta Structures, Inc.



Typical Pentahedral Connectors

Types and Applications

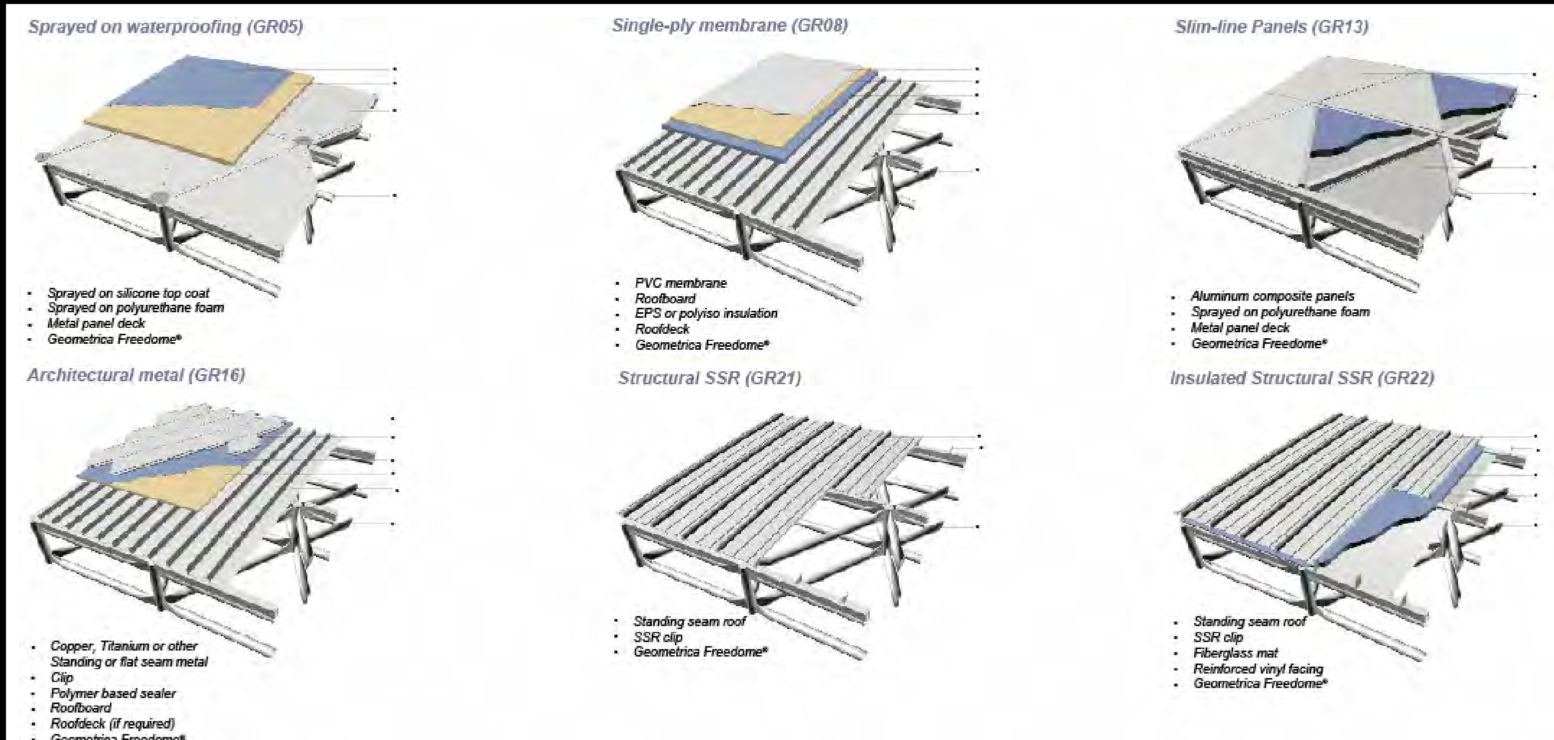
Delta Structures, Inc.



Typical Spherical Connectors

Types and Applications

Geometrica



Typical Cladding Types

Types and Applications

Geometrica

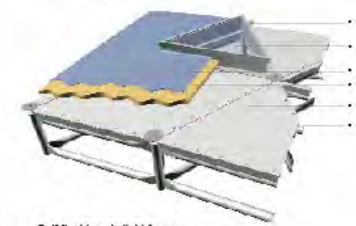
Clearstory light (GL23)

- Architectural metal or SSR
- Flashing and counter flashing
- Glass or polycarbonate
- Aluminum frame
- Geometrica Freedome®

Acoustic Ceiling 2 (GR38)

- Standing seam roof
- SSR clip
- Reflective vapor barrier
- Mineral wool
- Perforated metal panel
- Geometrica Freedome®

Triangular panel skylight (GL05)



- Self flashing skylight frame
- Heat strengthened glass
- Sprayed on or single-ply roof membrane
- Insulation
- Metal panel deck
- Geometrica Freedome®

Acoustic Ceiling 1 (GR33)

- Standing seam roof
- Mineral wool
- SSR clip
- Acoustic perforated roofdeck
- Geometrica Freedome®

Clear panel light (GL45)

- Cellular polycarbonate
- Aluminum mullion
- Geometrica Freedome®

Flush glazing(GL48)

- Insulated glass unit
- Aluminum mullion
- Geometrica Freedome®

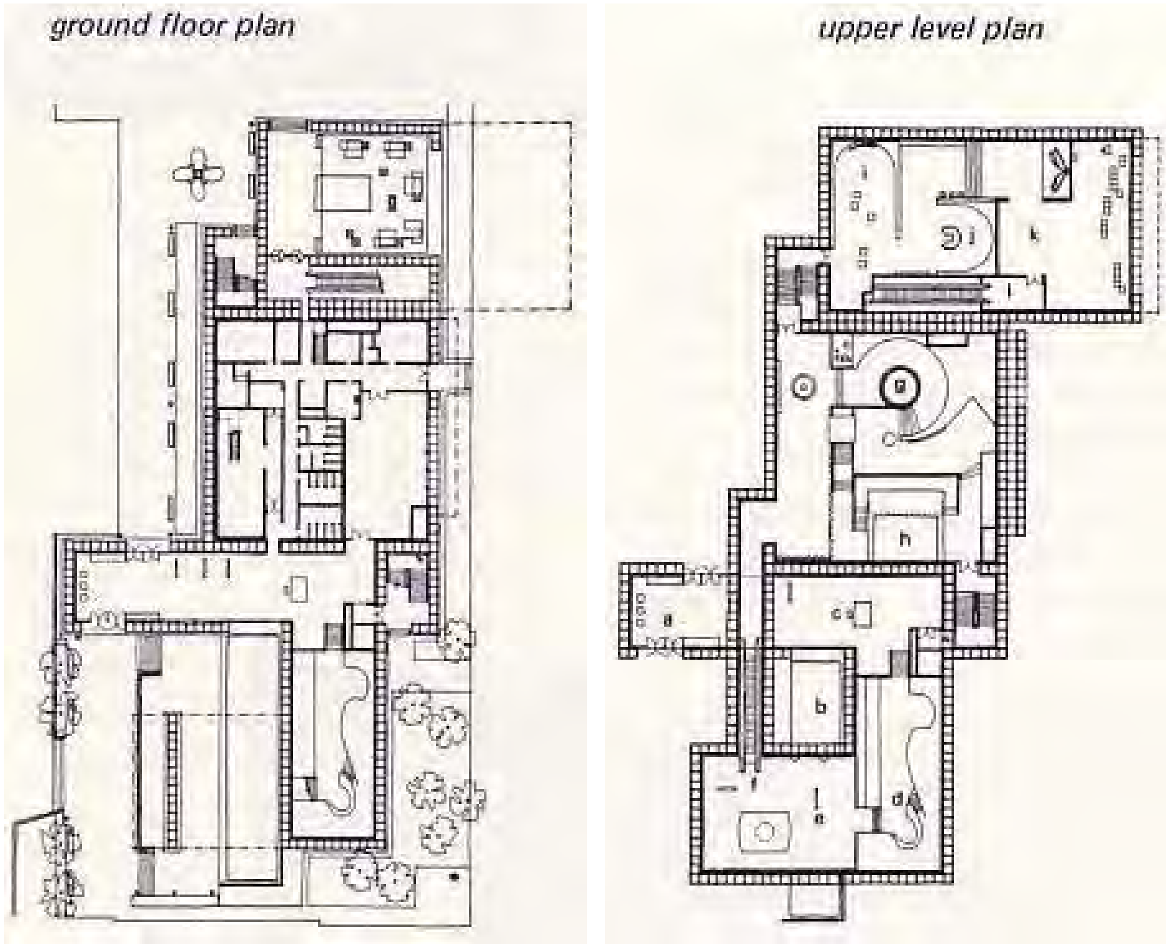
Typical Cladding Types

Types and Applications

Space frames have a history of diverse terrestrial applications including large temporary exhibition and permanent public/ commercial structures.

- A notable example is the Expo ’67 Netherlands Pavilion designed by Walter Eijkelenboom and Abraham Hiddlehoek (Netherlands) and George Eber (Canada):
  - The structure was comprised of 57,000 three foot segments of aluminum tubing (approximately 33 miles of total length).
  - The entire structure snapped together without welding to enable rapid assembly and disassembly following use.
  - The structure was expandable by adding more pieces, and accommodated an expansive cantilever.

Expo ’67 Netherlands Pavilion



Expo ’67 Netherlands Pavilion

Flat Enclosures

The Stansted Airport Terminal in London designed by Foster and Partners (constructed in 1991) has a space frame roof comprised of inverted pyramid trusses covered by 22,000 triangular ceiling panels.

- The roof structure appears to float above the open one-storey space:
  - The base of each truss structure is a "utility pillar" which provides indirect up-lighting illumination along with HVAC, water, telecommunications and electricity.
  - The roof is glazed to admit diffuse natural light.

Foster and Partners

Stansted Airport Terminal

Flat Enclosures

Foster and Partners

Stansted Airport Terminal

Flat Enclosures

SPECIAL STRUCTURES

SPACE FRAMES

Koch + Partner

The Munich Airport Terminal - 2, designed by Koch + Partner and constructed in 1998, won the European Award for Steel Structures, 2005 in Germany.

- The award decision was based upon the building's transparency and functionality:

- Its spacious light-flooded check-in hall emphasizes expansive scale and aesthetics of structural detail.
- Covering about 300,000 m^2 of surface area, the space frame roof is comprised of seven bays, each with four elements (main columns, main framework girders, secondary girders and substructure).
- The main columns, spaced at 10 m centers, are constructed of 660 mm diameter steel tubes.
- The substructure, made of longitudinal and transverse rolled steel girders, incorporates trapezoidal sheets and skylight glazing.

Munich Airport Terminal - 2

Koch + Partner






Munich Airport Terminal - 2

Flat Enclosures

Built in the early 1980's, the Jacob K. Javits Center in New York is one of the largest single-area space frame structures in the world.

- The building spans an area of 53,000 m2 (300 m x 165 m), and is 47 m high at the entrance hall:
  - Structural bays (27 m x 27 m) are constructed of steel tubes varying between 75 mm-215 m diameters to carry compressive loads, and high-tensile steel rods that carry tensile loads.
  - The structure is divided into several independent large areas bounded by diamond trusses with paired chords to accommodate thermal movements of the immense facility.
  - Space frame walls and ceilings are clad in semi-reflective glass to provide natural illumination.

I.M. Pei

Javits Center, New York

Flat Enclosures

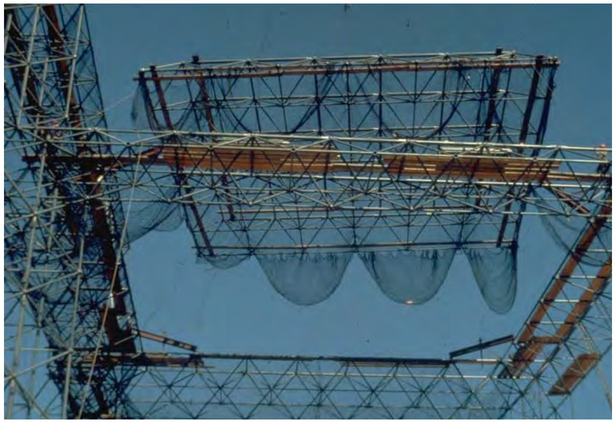
I.M. Pei

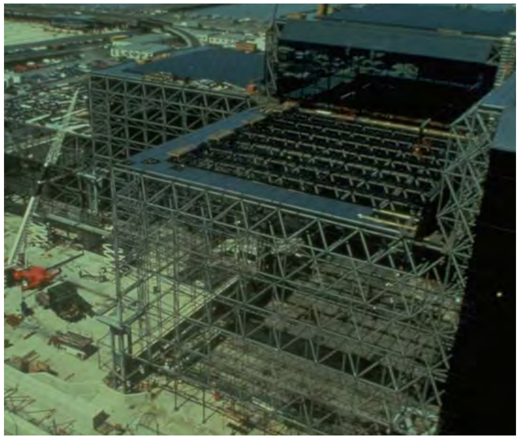
Javits Center, New York

Flat Enclosures

MS-SPACE ARCHITECTURE
SICSA

I.M. Pei

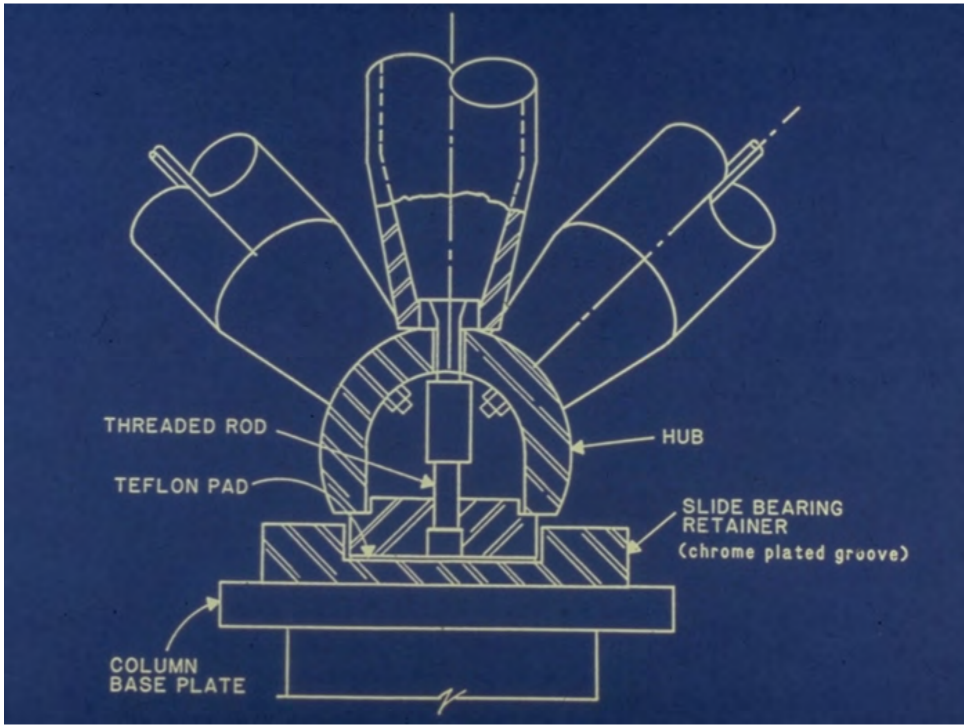


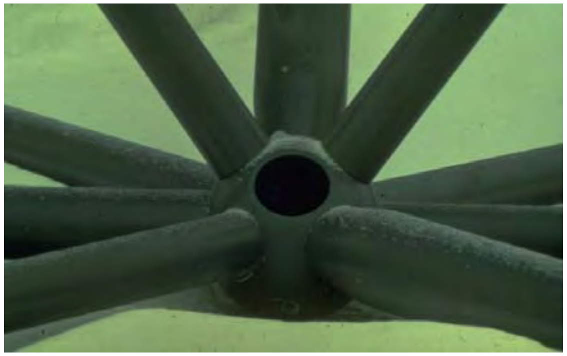


Jarvits Center Construction

Flat Enclosures

I.M. Pei





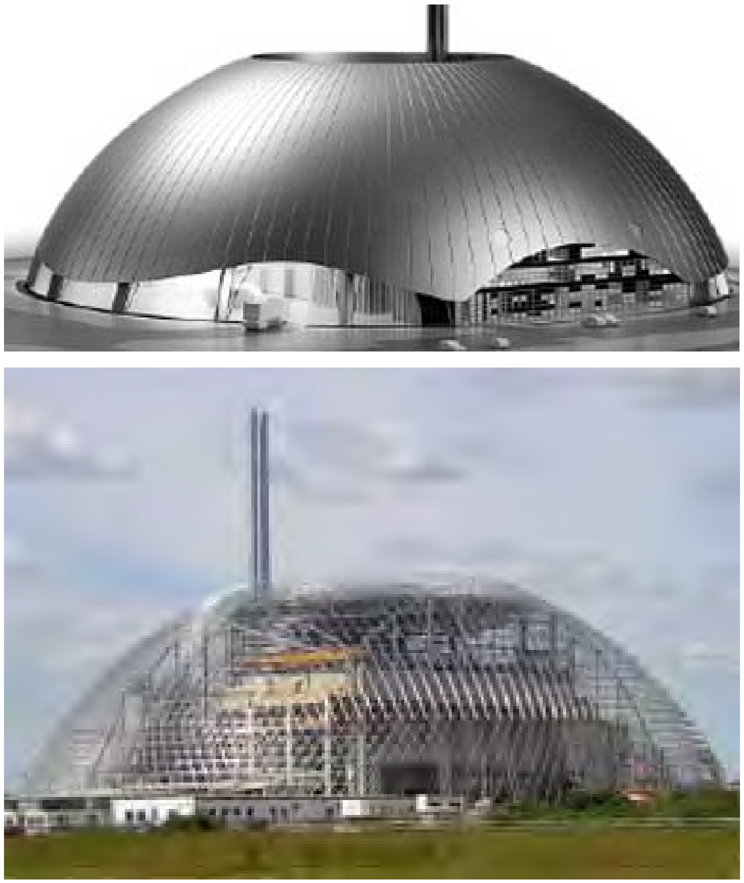
Javits Center Connection Details

Flat Enclosures

Geometrica

The Marchwood Energy Recovery Plant design applied lightweight modular principles of geodesic structures to create a domed covering that was added while the plant was also under construction.

- The 110 m diameter, 36 m high structure is clad in aluminum and is completed with a lower level skirt of windows that curve around the base to provide natural illumination and operational viewing.



Domed Energy Recovery Plant, Marchwood, UK

Curved Enclosures

Kisho Kurokawa

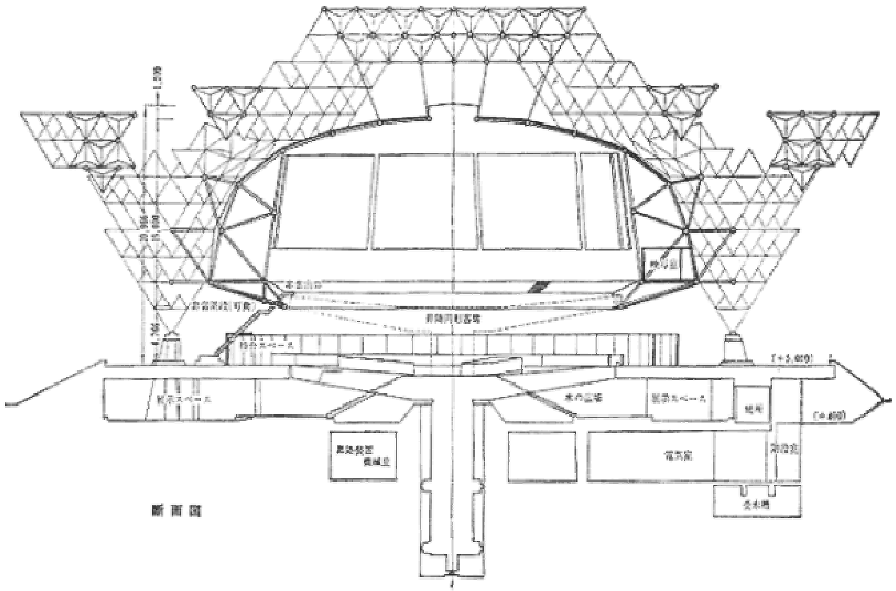
The Toshiba Ihi Pavilion tetra space frame structure is based upon tetrahedron component units that allow the system to grow in 14 directions according to a geometry of three-dimensional coordinates.

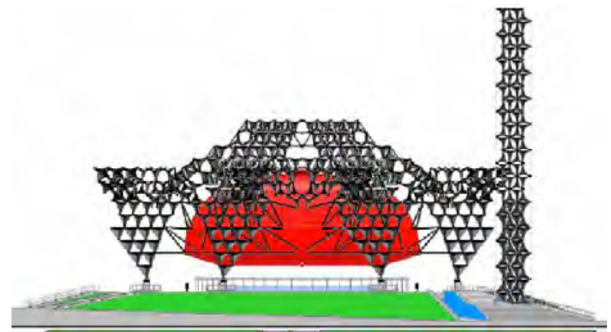
- The structure is comprised of 1,444 tetra-units, and rises above a central pedestal structure:
  - Four types of tetra-units were used, each with a different strength as required at various locations.
  - A 300 ton theater structure was raised and lowered by an oil hydraulic lift within the space frame envelope.
  - The building was intended to be used only for the six month long exhibition period, and was then dismantled with the components melted down and recycled.

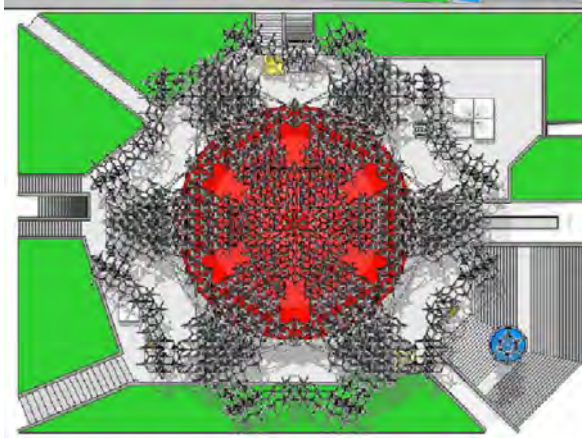
Toshiba Ihi Pavilion, Expo '70

Curved Enclosures

Kisho Kurokawa



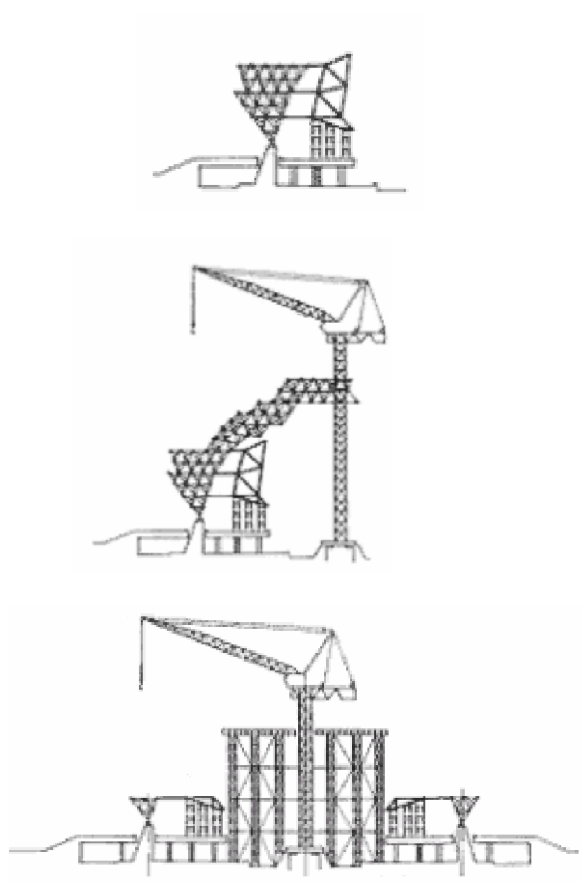




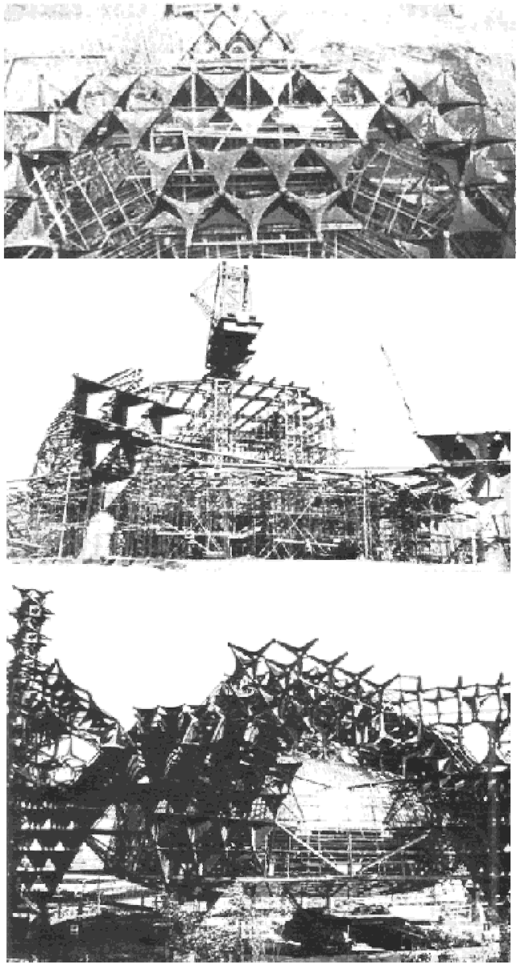
Toshiba Ihi Pavilion, Expo ’70

Curved Enclosures

Kisho Kurokawa



Building Construction



Curved Enclosures

SPECIAL STRUCTURES

SPACE FRAMES

MS-SPACE ARCHITECTURE SICSA

Kisho Kurokawa

Toshiba Ihi Pavilion, Expo '70

Symbolic Tower Structure

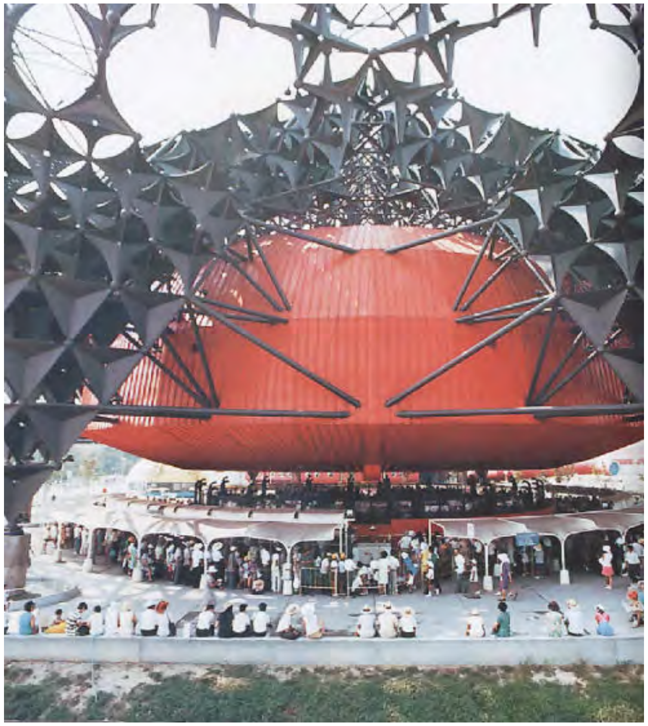
Curved Enclosures

SPECIAL STRUCTURES

SPACE FRAMES

Kisho Kurokawa

500 Seat Theater Within Structure



Toshiba Ihi Pavilion, Expo '70

Curved Enclosures

Kisho Kurokawa

Toshiba Ihi Pavilion, Expo '70

Curved Enclosures

SPECIAL STRUCTURES

SPACE FRAMES

Go to the list of contents

SUMMARY CONCLUSIONS:

Types and variations of shelters for people, their activities and their support needs are virtually unlimited. Throughout recorded history humans have adapted their habitats to expanded environmental venues, evolutionary cultural developments, changing mobility and community patterns, technology and tool advancements, and diverse survival imperatives. This report presents only a very small sampling of possible examples which are organized around general types of design and construction approaches.

Lessons and Imperatives

CONCLUSIONS

FINAL WORDS

Practical and effective design and construction to meet current and future needs represents enormous challenges and opportunities for interested professionals who wish to engage real problems facing populations of all economic strata throughout our world and beyond. It is therefore incumbent upon those academic institutions who train them and advance new analytical and construction methods to recognize such priorities. Our responses to human shelter needs and technologies in extreme environments and under severe conditions of poverty and disaster can offer important solutions and lessons that advance progress everywhere.

Lessons and Imperatives

CONCLUSIONS

FINAL WORDS

Additional information relevant to this section can be found in Part I, Section E (robotic and mobility systems) of this SICSA SPACE Architecture Seminar Lecture Series, along with other publications listed below:

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CONCLUSIONS

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CONCLUSIONS

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