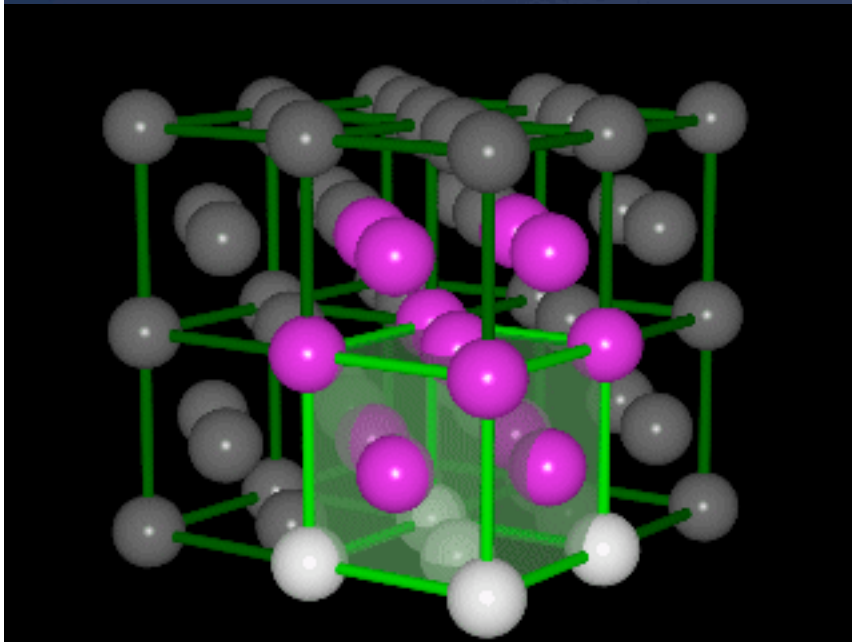


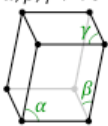
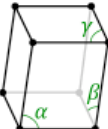
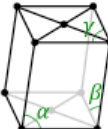


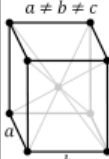

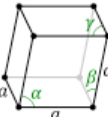
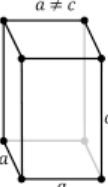
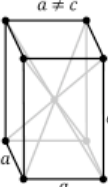

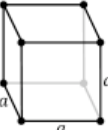
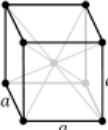
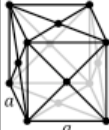
Sticks as Bones:

wood, lattices, weak structure
and the Ten Thousand Things

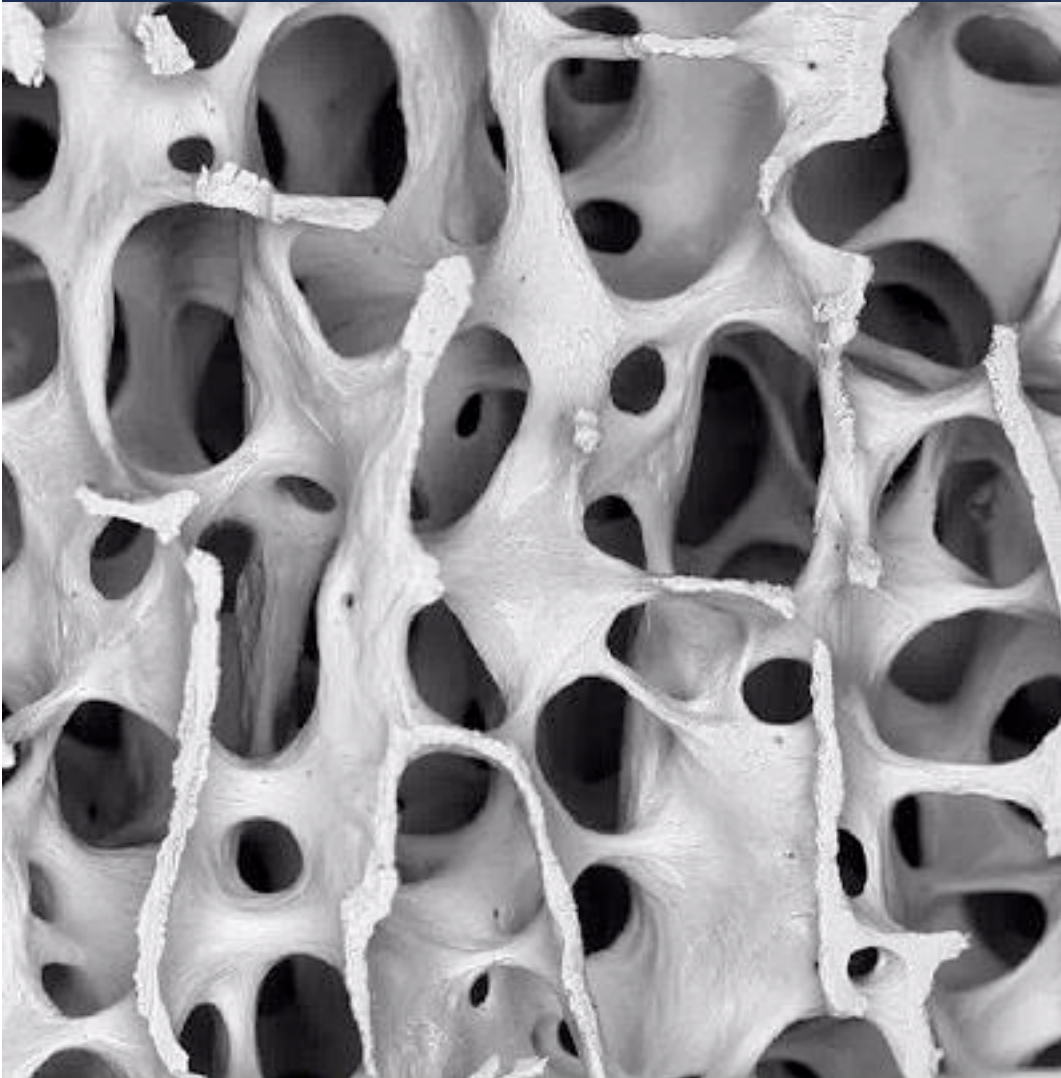


Lattice Structure:

An open framework made of strips of metal, wood, or similar material overlapped or overlaid in a regular, usually crisscross pattern.

The 7 lattice systems (From least to most symmetric)	The 14 Bravais Lattices				Examples
1. triclinic (none)	$\alpha, \beta, \gamma \neq 90^\circ$ 				
2. monoclinic (1 diad)	simple	base-centered			
	$\alpha \neq 90^\circ$ $\beta, \gamma = 90^\circ$ 	$\alpha \neq 90^\circ$ $\beta, \gamma = 90^\circ$ 			
3. orthorhombic (3 perpendicular diads)	simple	base-centered	body-centered	face-centered	
	$a \neq b \neq c$ 	$a \neq b \neq c$ 	$a \neq b \neq c$ 	$a \neq b \neq c$ 	
4. rhombohedral (1 triad)	$\alpha = \beta = \gamma \neq 90^\circ$ 				
5. tetragonal (1 tetrad)	simple	body-centered			
	$a \neq c$ 	$a \neq c$ 			
6. hexagonal (1 hexad)					
7. cubic (4 triads)	simple (SC)	body-centered (BCC)	face-centered (FCC)		
					

Common in Crystals and Metals



Nature's Lattices:
Many small parts
bracing each other, a
stiff redundant
structure

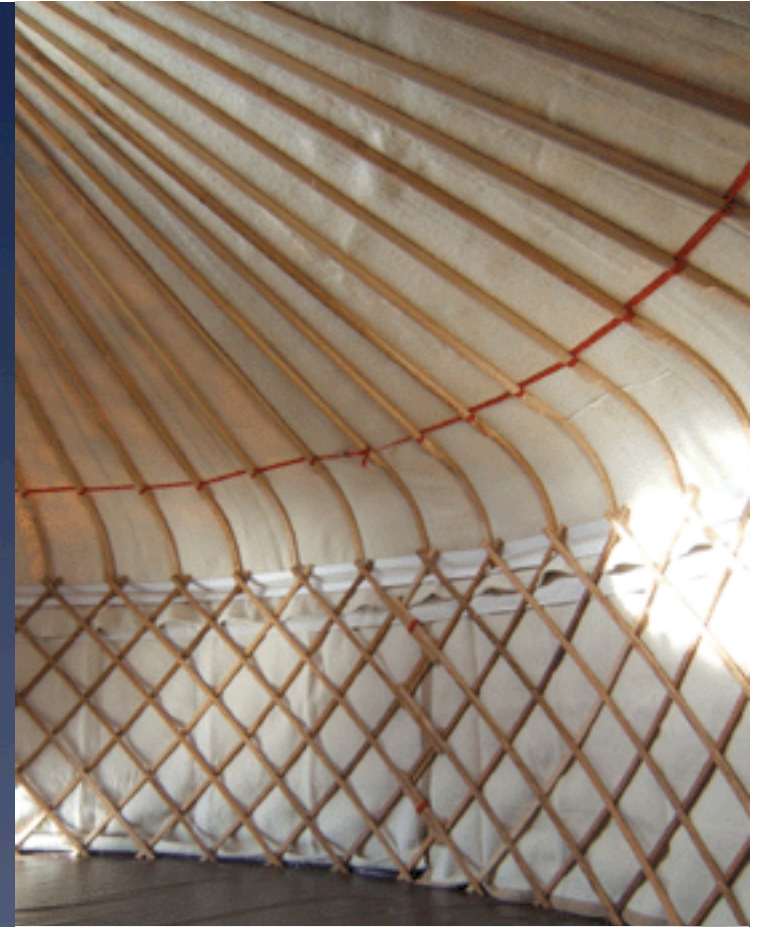
Electron Microscope image of
Spinal Vertebrae Section

...can we build as nature does?

From Turkmenistan... the Yurt, traditional, portable, foldable, lattice shelter

Central Asia origins, developed by nomadic sheepherders

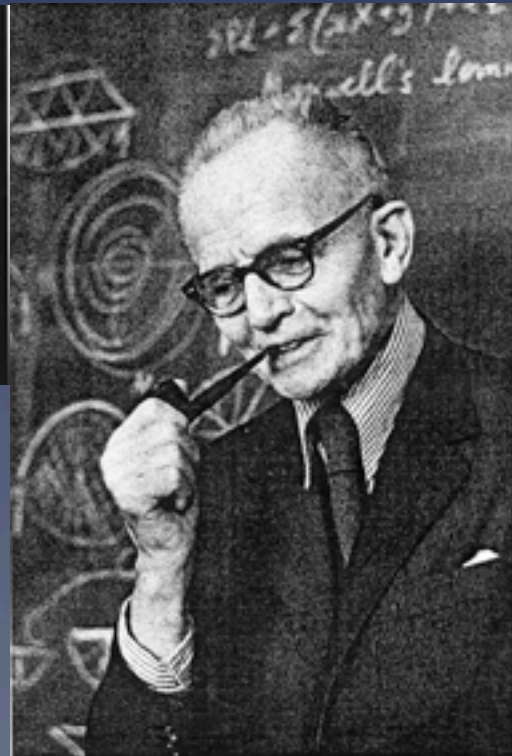
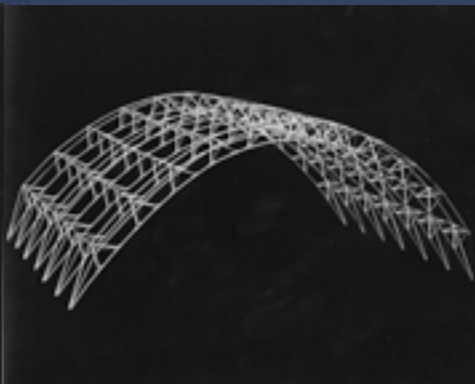
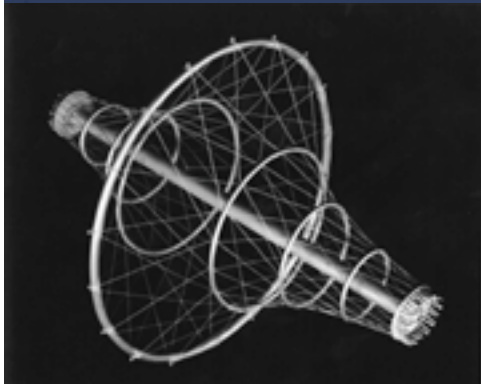
Uses many small elements as structure in lieu of a traditional column-beam hierarchy



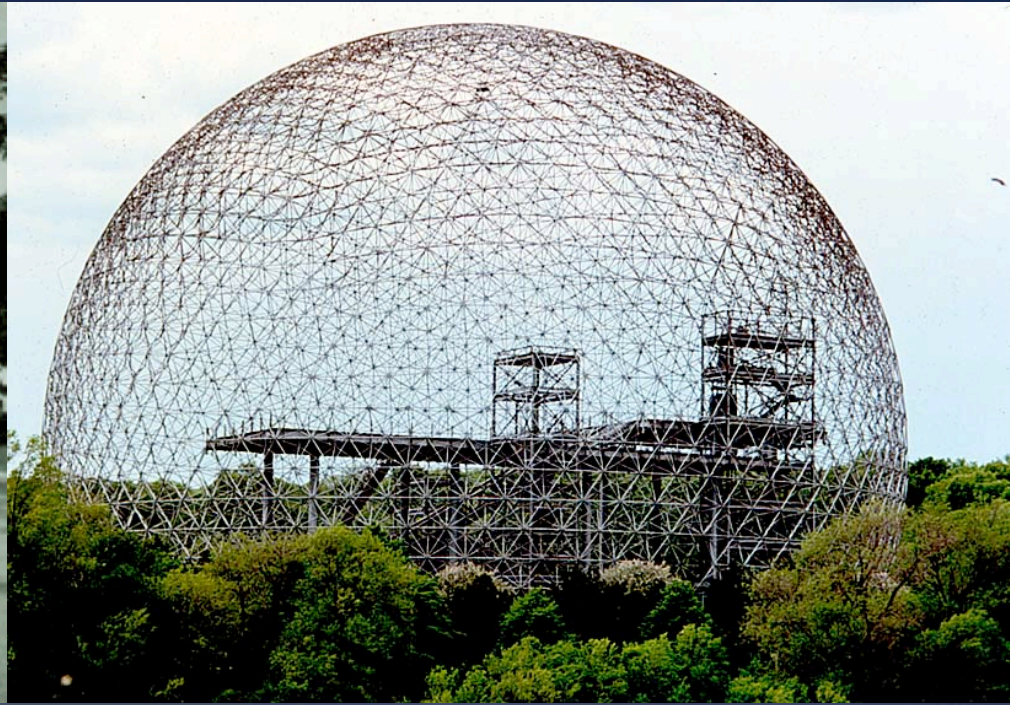


Dependent on a uniform distribution of loads across the many small elements.

Local point loading can cause collapse unless designed to shed load to adjacent members



"The art of structure is where to put the holes" **Robert le Ricolais**

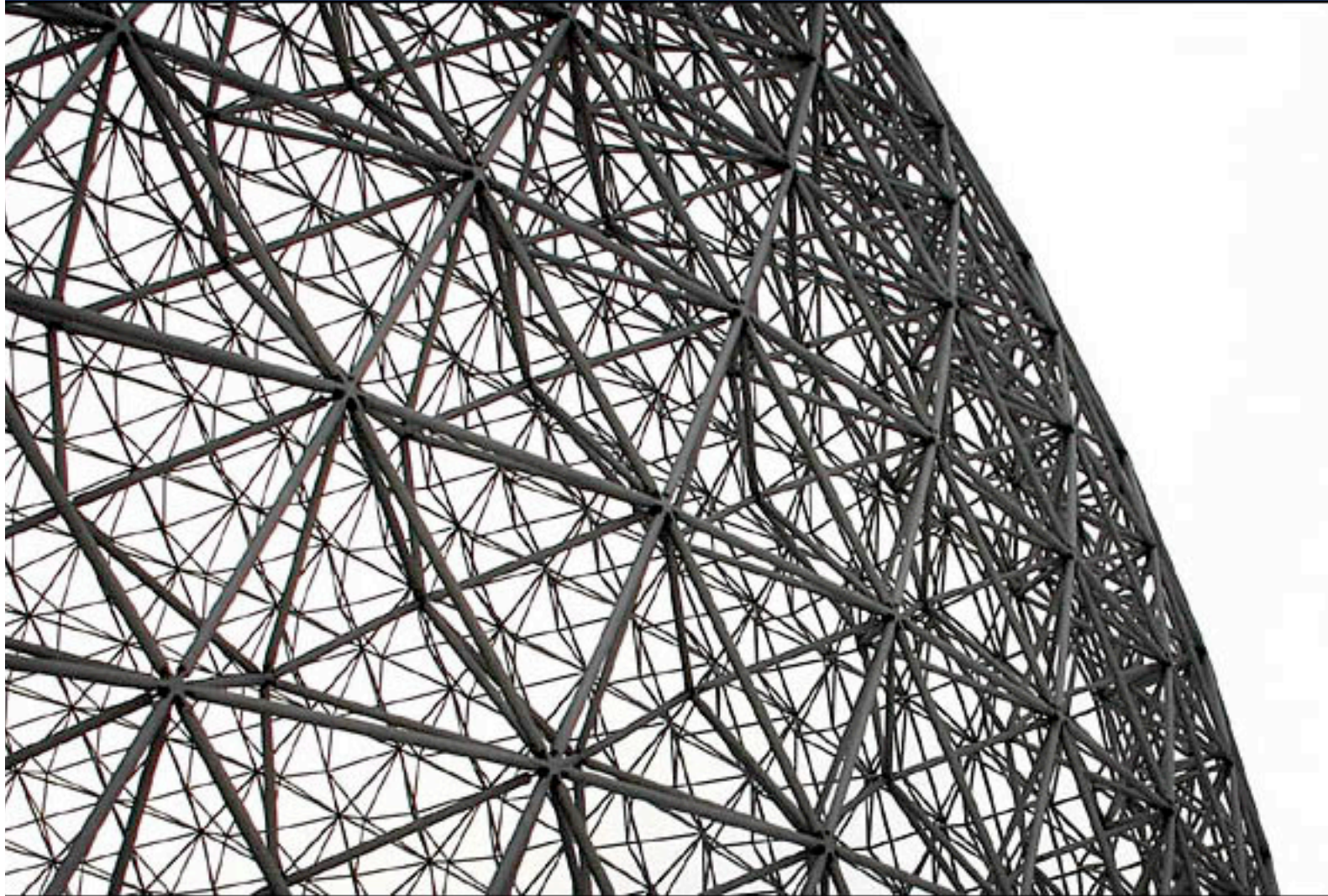


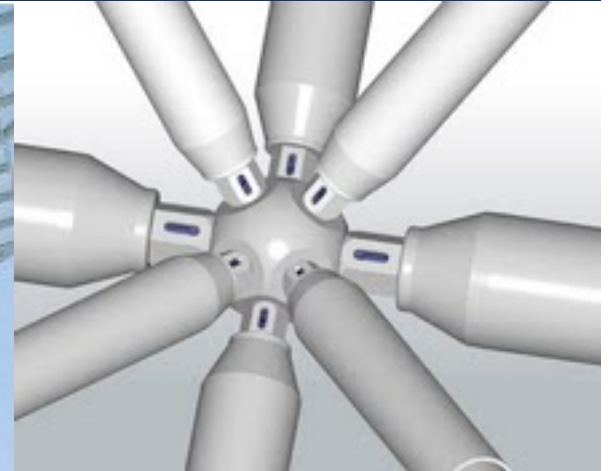
Buckminster Fuller 1895-1983

Developed the principle of the Geodesic Dome, a three dimensionally triangular lattice...often constructed as a space frame... early ecologist, wrote "Operating Manual for Spaceship Earth (1963)"

- "Don't fight forces, use them."
- "As a consequence of the slavish "categoryitis" the scientifically illogical, and as we shall see, often meaningless questions "Where do you live?" "What are you?" "What religion?" "What race?" "What nationality?" are all thought of today as logical questions. **By the twenty-first century it either will have become evident to humanity that these questions are absurd and anti-evolutionary or men will no longer be living on Earth.**"
- "Topology provides the synergetic means of ascertaining the values of any system of experiences. Topology is the science of fundamental pattern and structural relationships of event constellations."



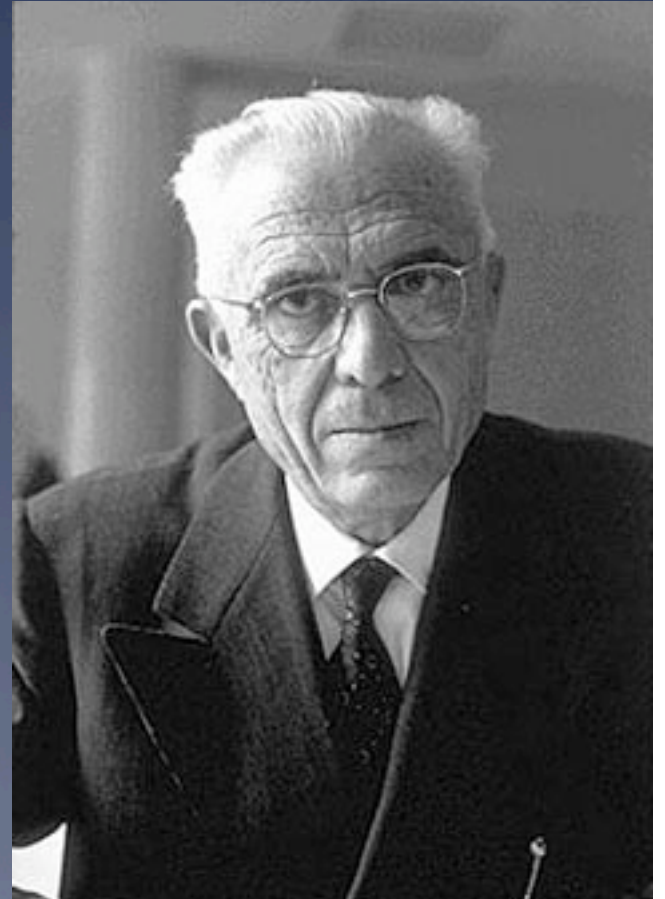




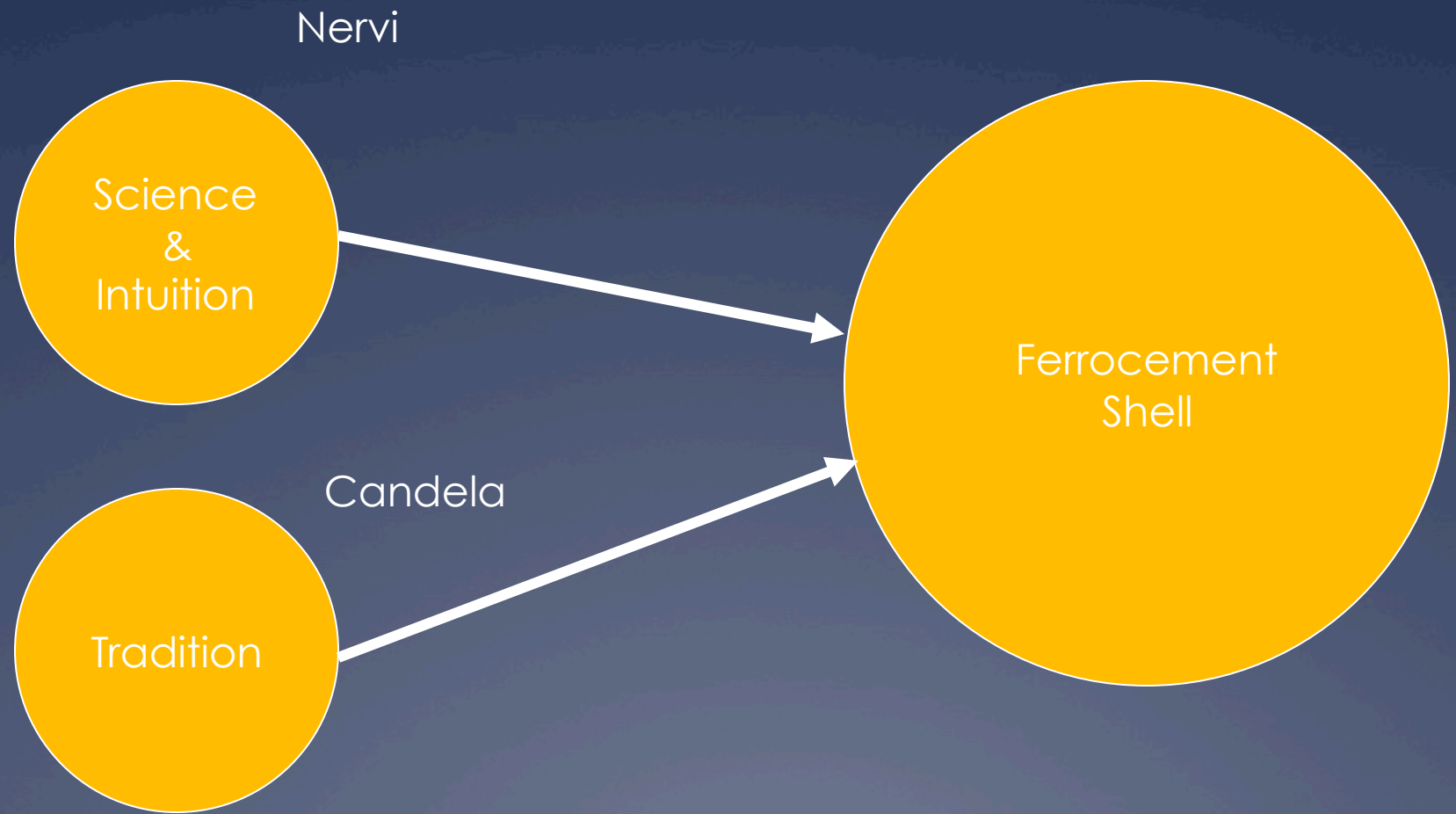
Step 1: Peter

Mastering the Shell Game

Luigi Nervi



Two paths to the shell



Pier Luigi Nervi 1891-1979

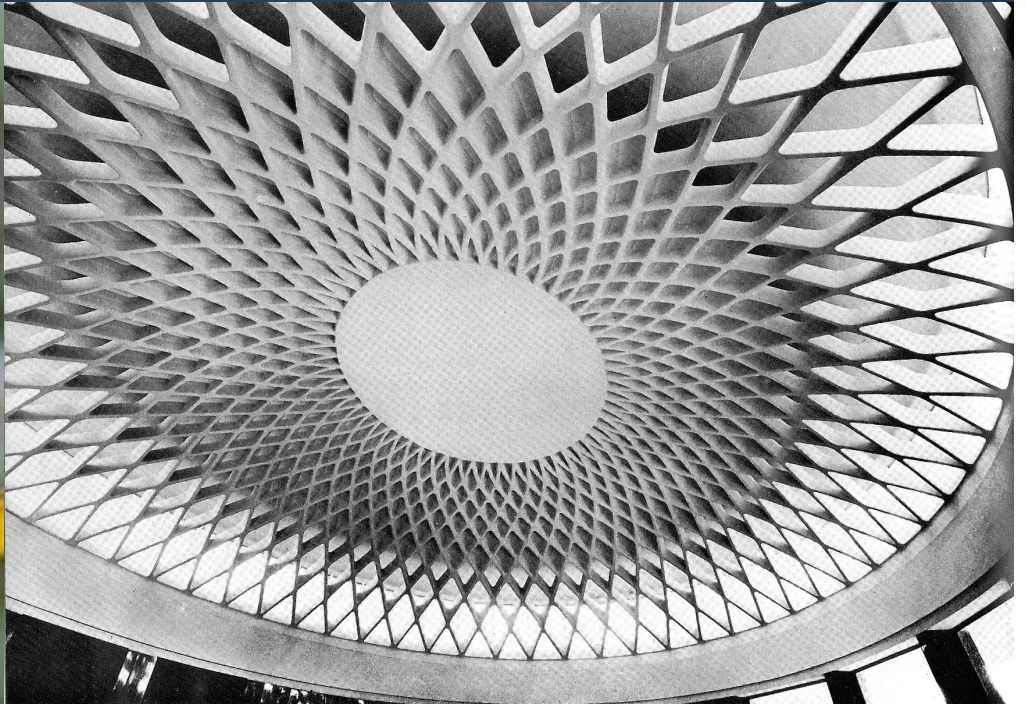
- * Architecture: Technology meets Art
 - * Like Maillart, only put material where there are forces
 - * The most **natural way** of conducting and directing forces to the earth, with the least amount of material yielded the most truth

Gothic Inspiration

- * “a pattern that suggests the isostatic lines of principal stress”
- * (isostatic: equilibrium in stress and reaction)



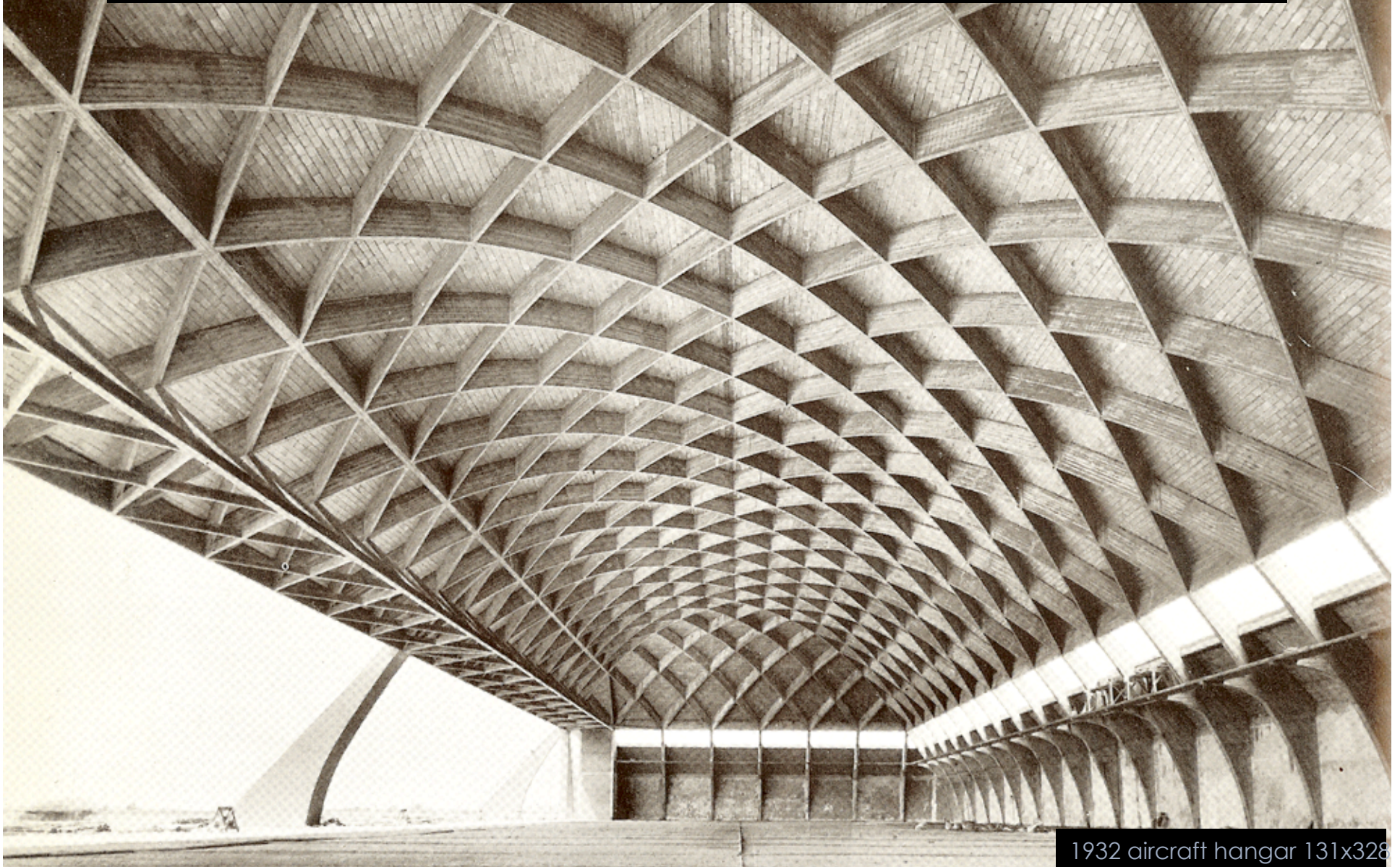
Is isostasy natural?



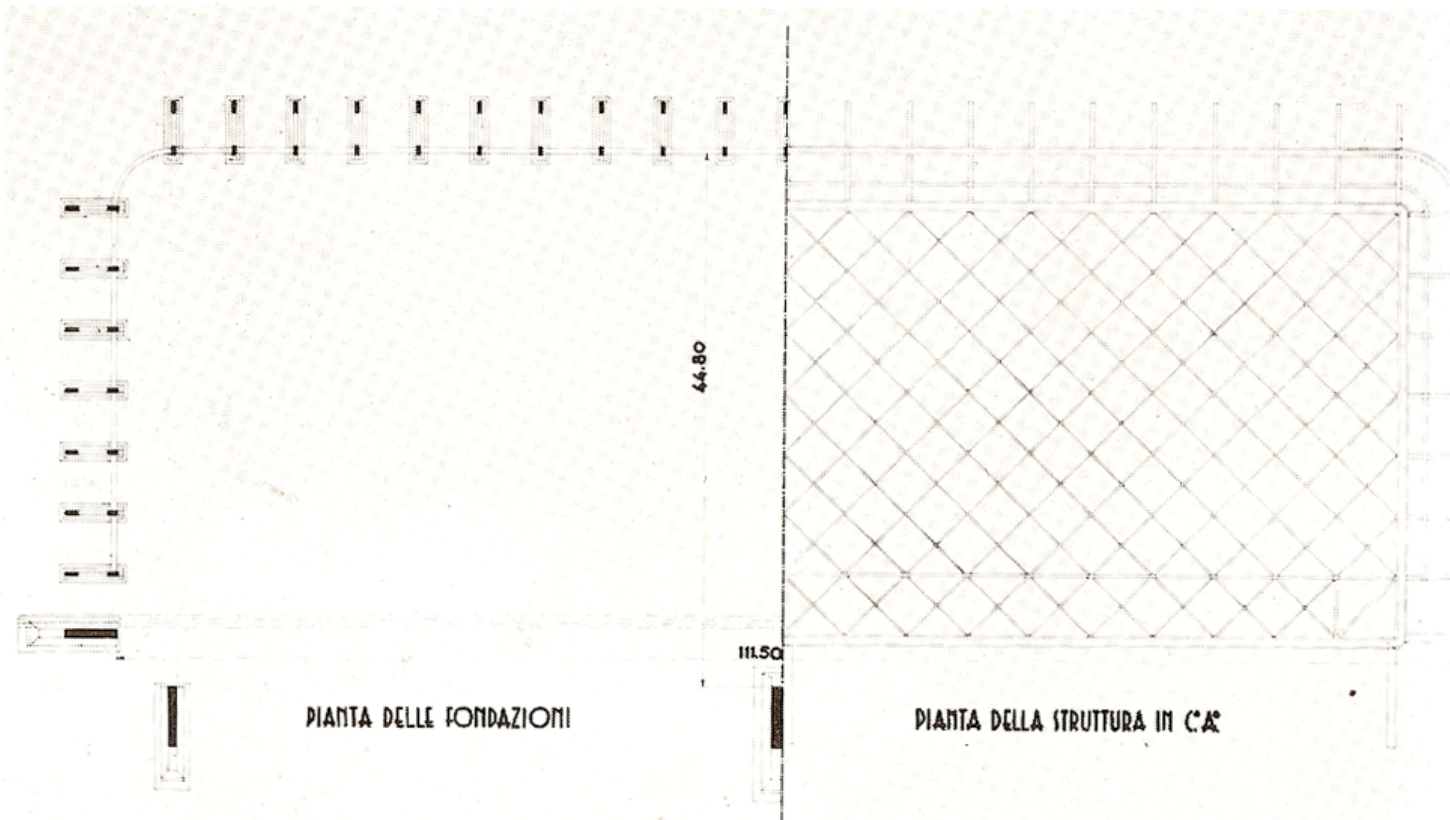
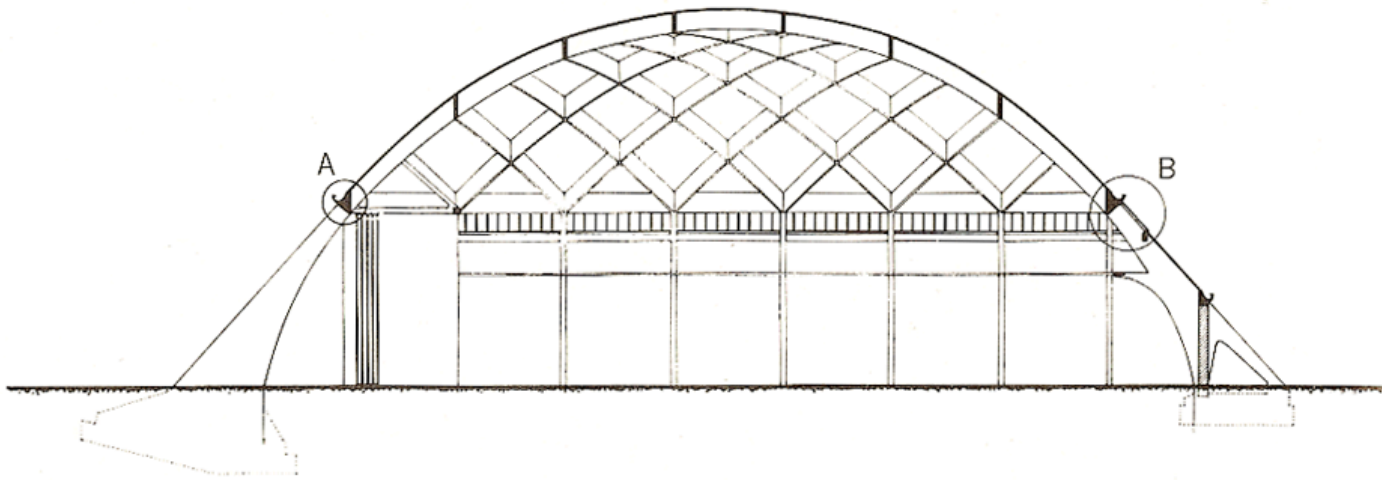
Most engineers agree, forces follow the ribs. Channeling through ribs means less material, more efficiency

After static balance...production 1932 aircraft

hangar

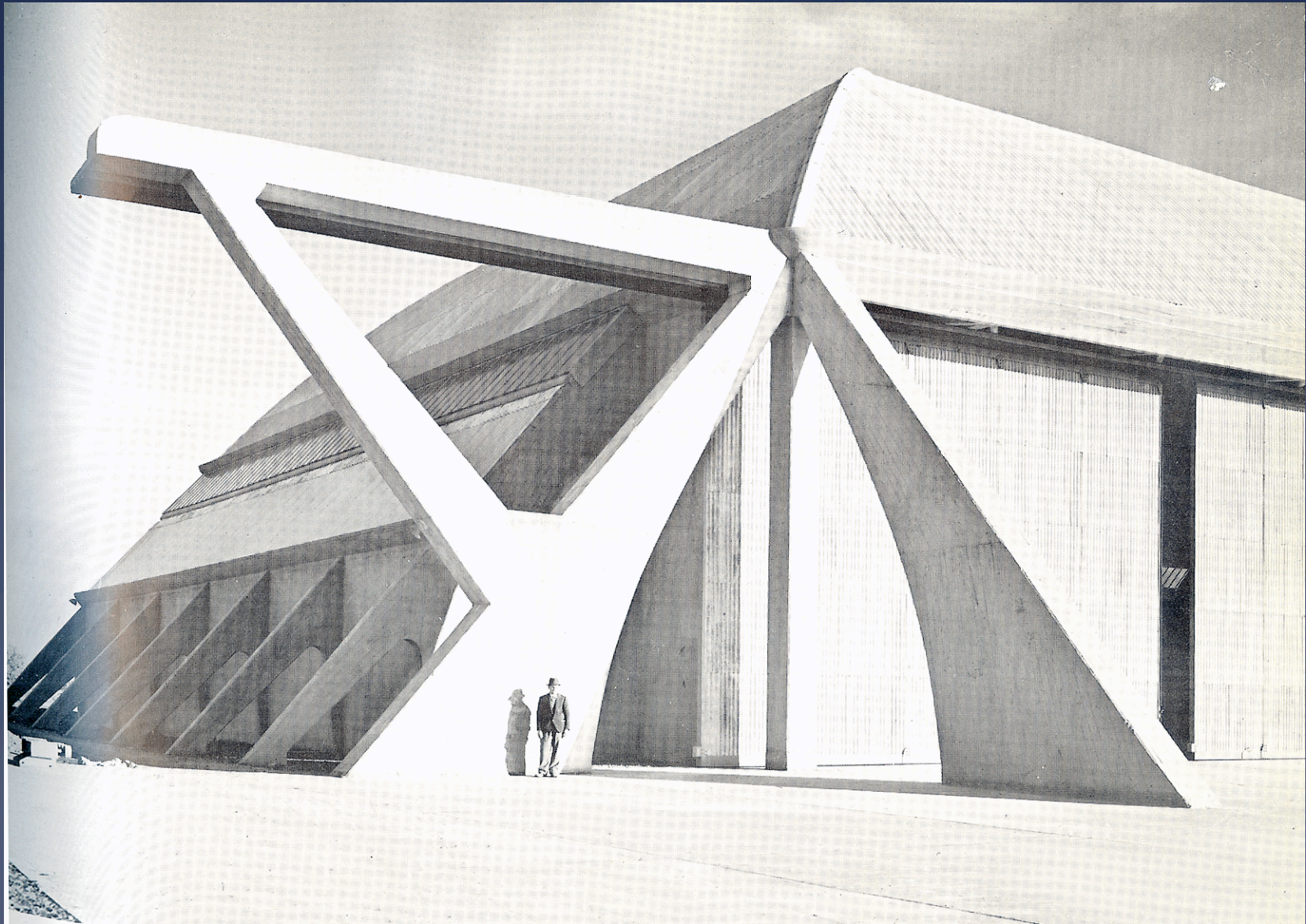


1932 aircraft hangar 131x328

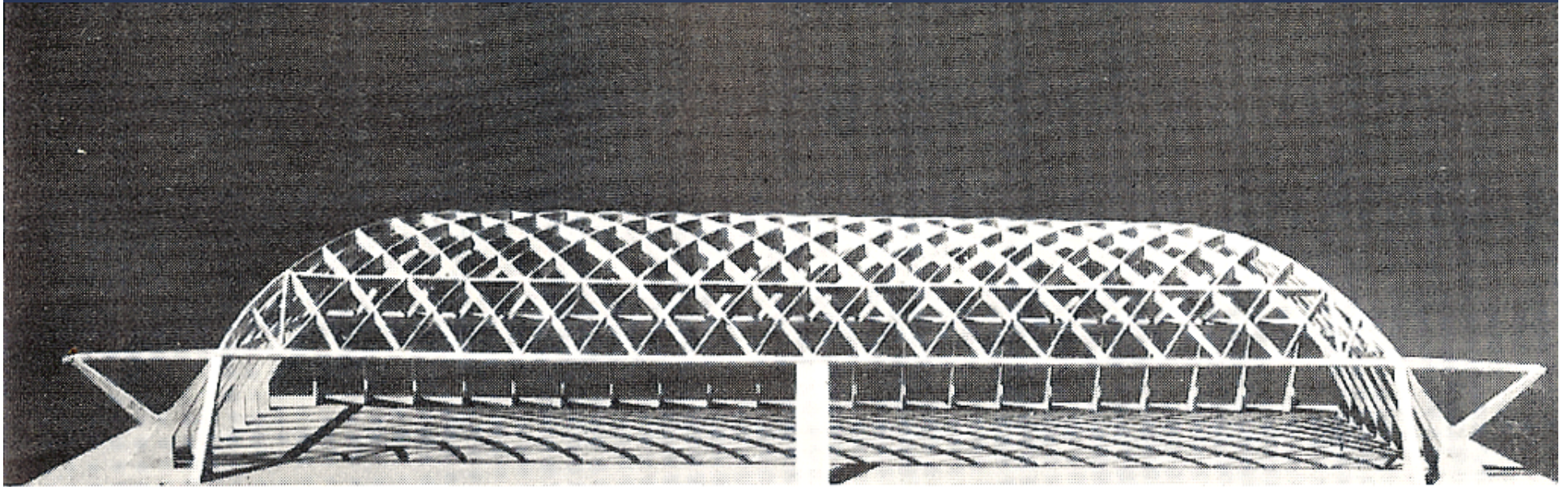


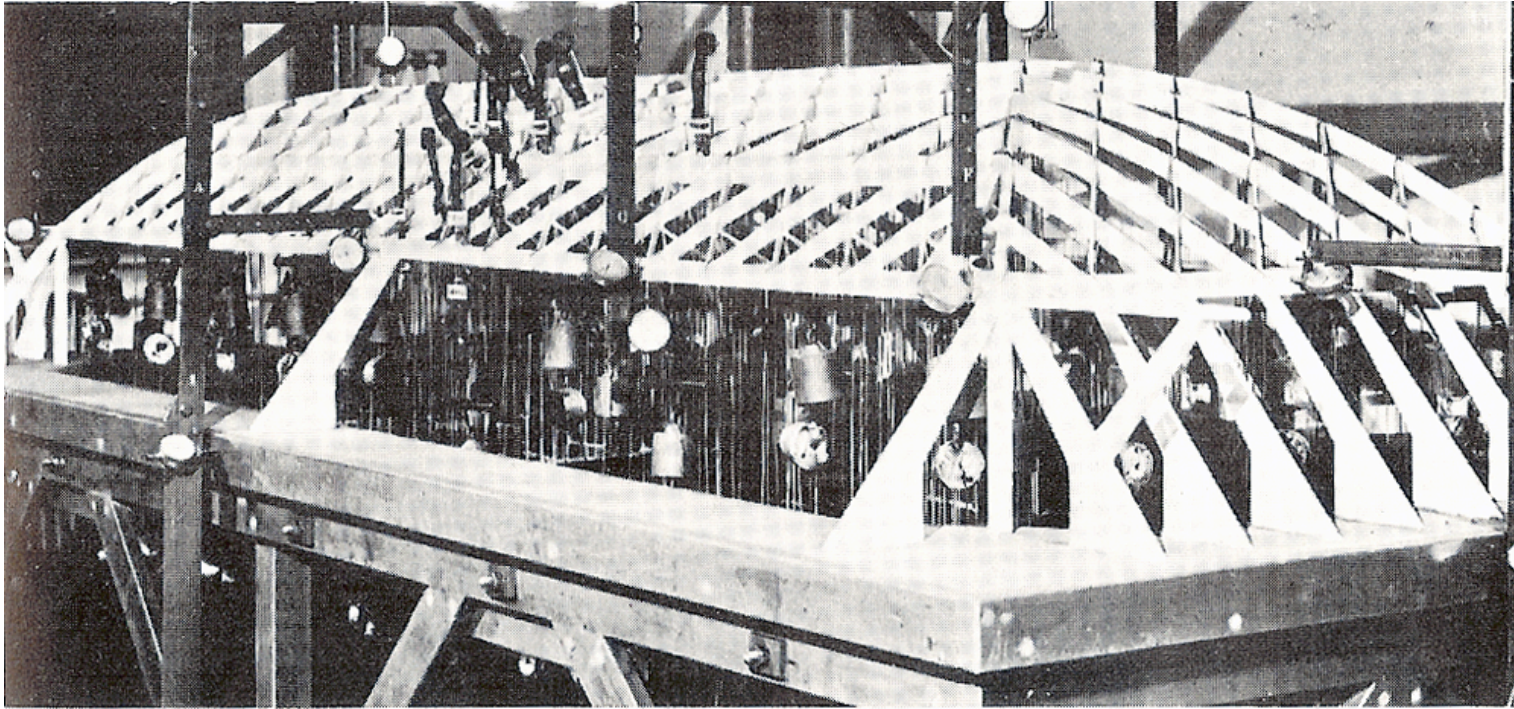
Why diagonal ribs?

Hipped Vault End? Why?

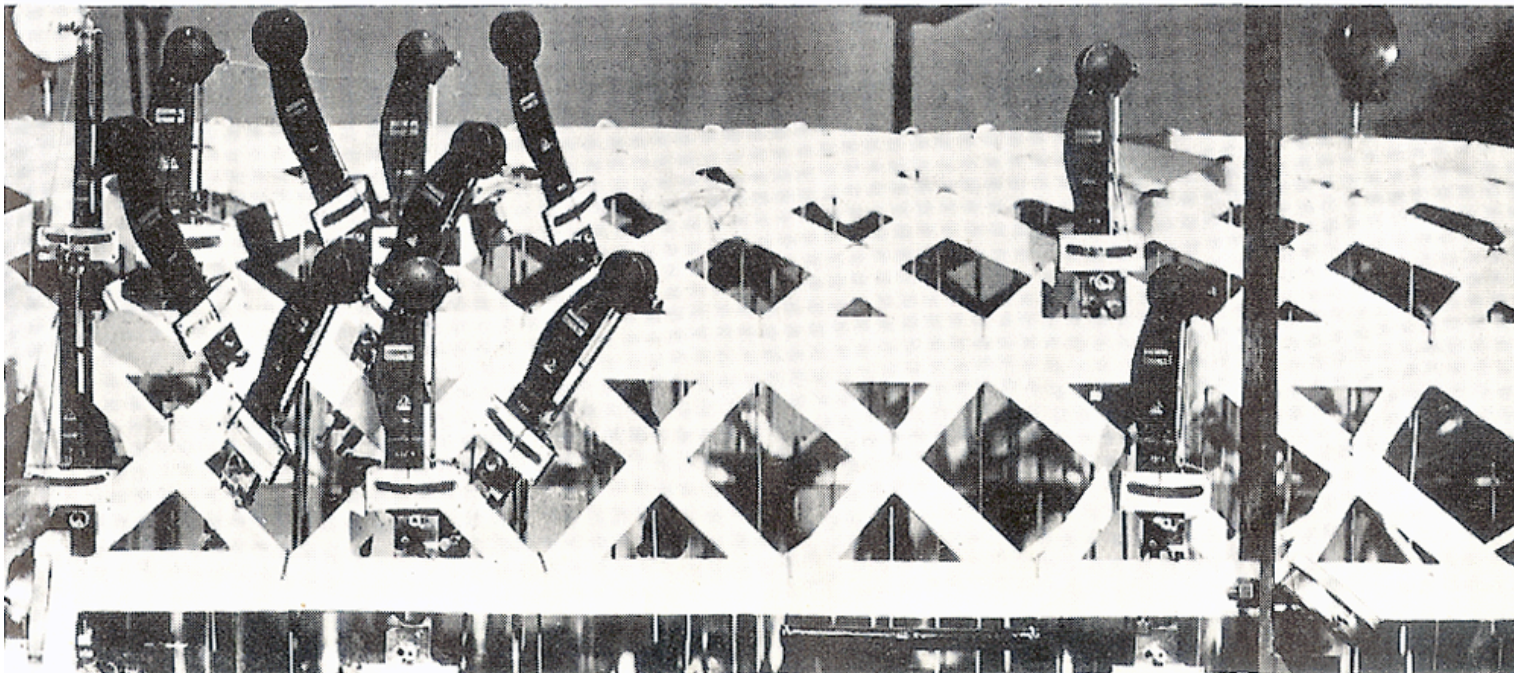


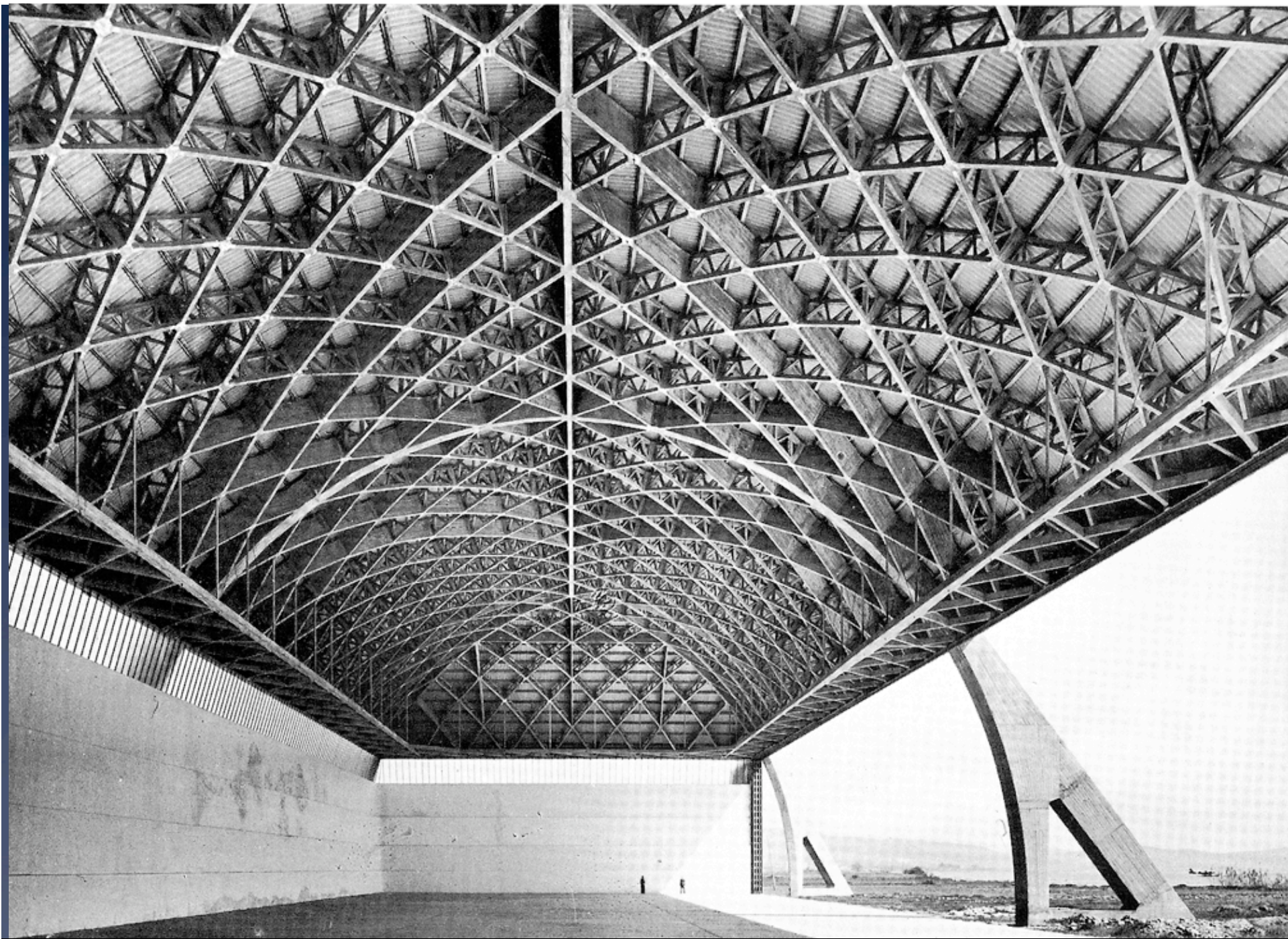
Model to learn





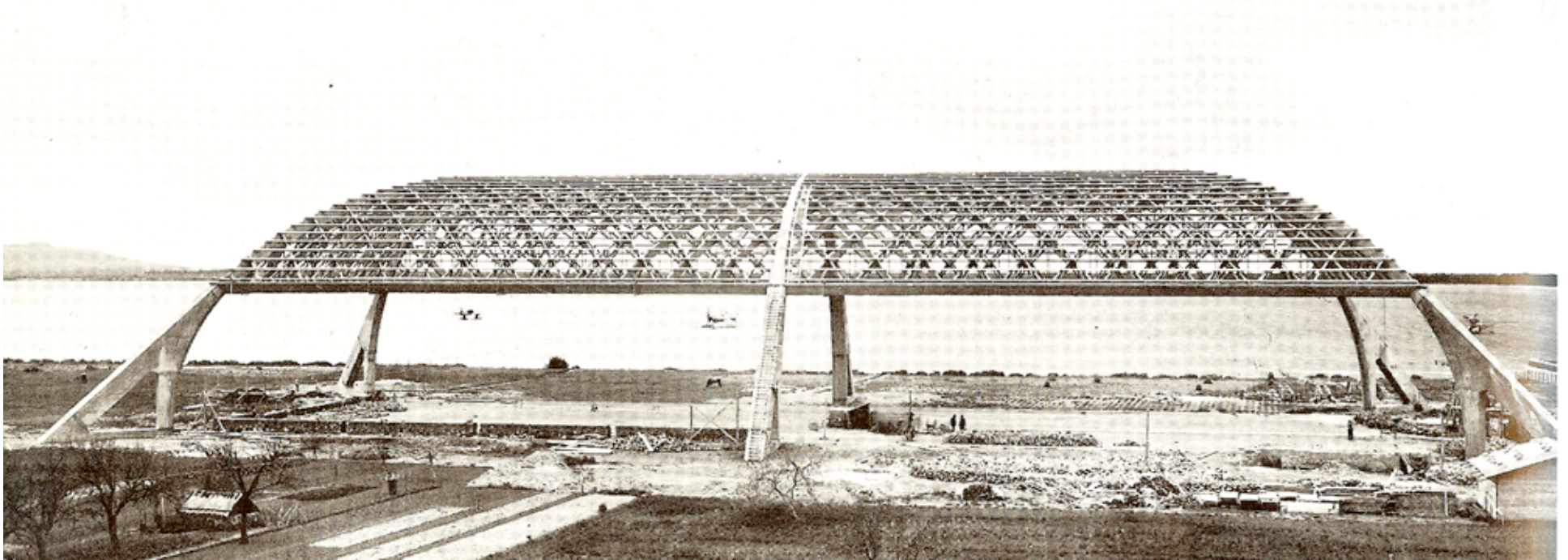
Test
models to
verify
numbers





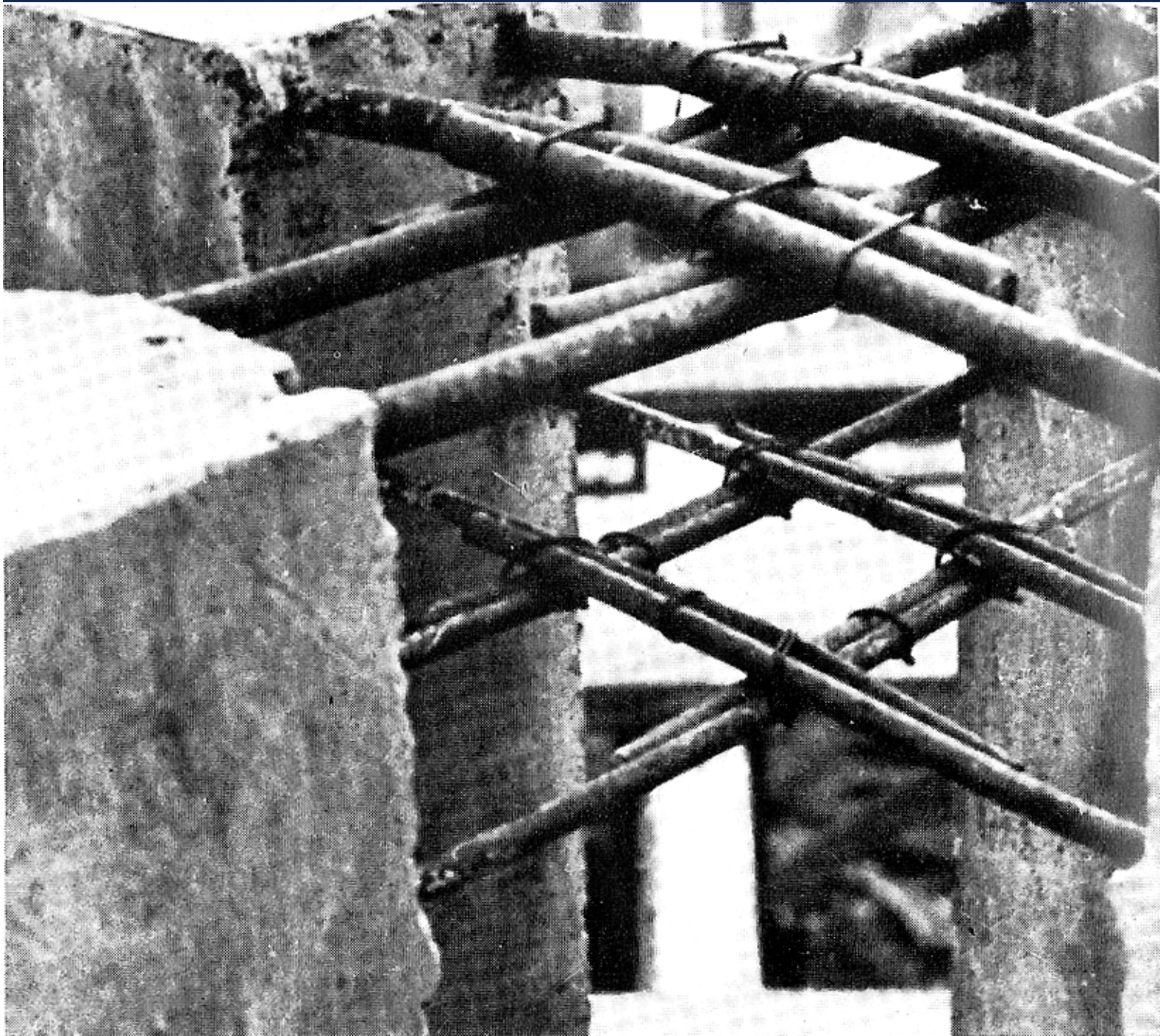
1939 aircraft hangar 132x328 new! Improved! Precast AND Sitecast!

Symmetry gives simpler form



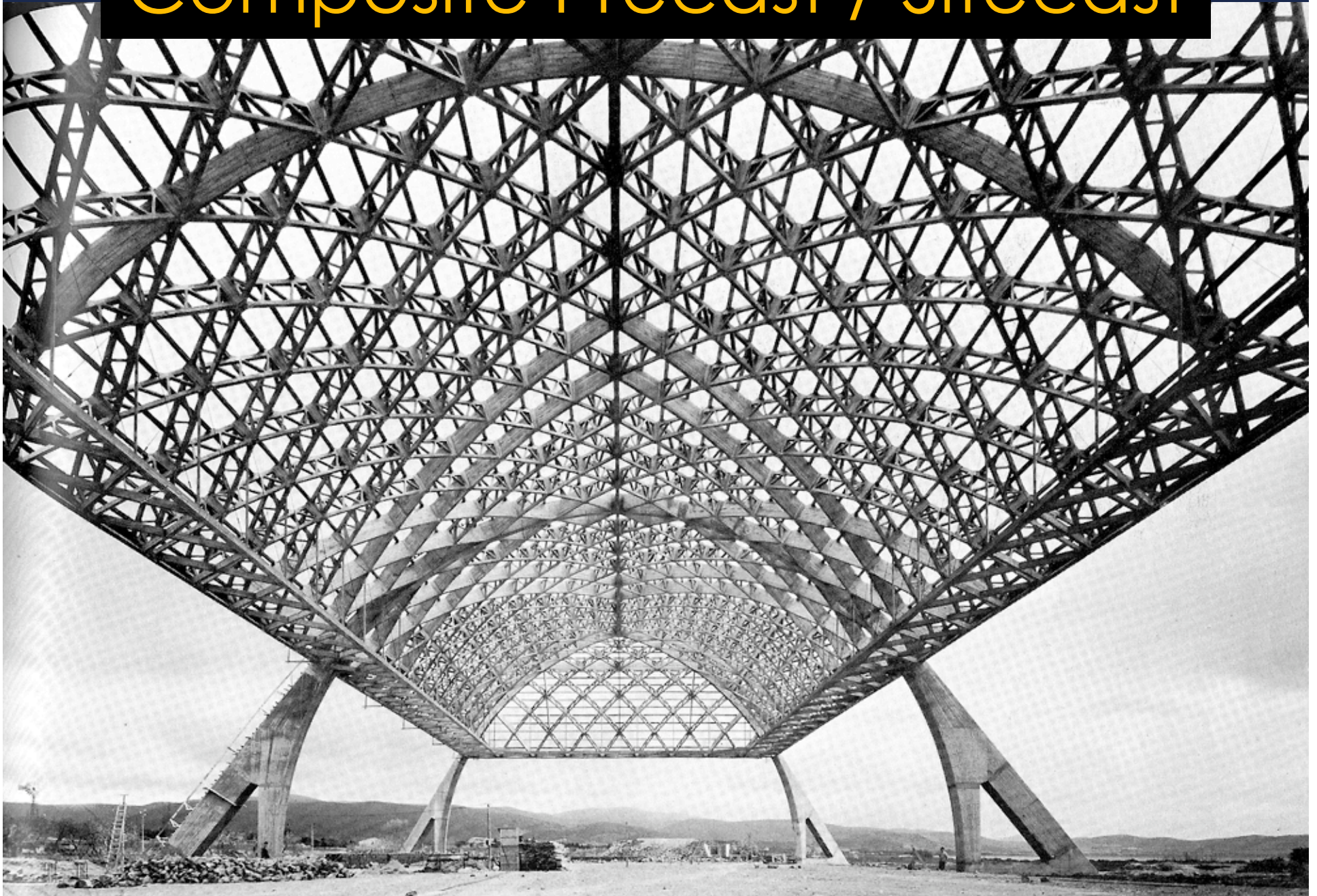
Onsite Precast Plant





Weld
&
Pour
to connect

Composite Precast / Sitecast



1943 patent "Ferrocement"



In 1943 Pier Luigi Nervi registered his patent of "ferro-cemento", an extremely thin structural plate, made of small diameter wire netting layers fixed on steel bars of a wider diameter, with cement mortar used as the binder. It was during war time. Pier Luigi Nervi was 52 years old and he had already had a successful career; his name, associated with the Florence stadium, with its well known helicoidal stairs, and with the Orbetello hangars, had become renowned worldwide.

Almost equal parts steel and
cement/sand

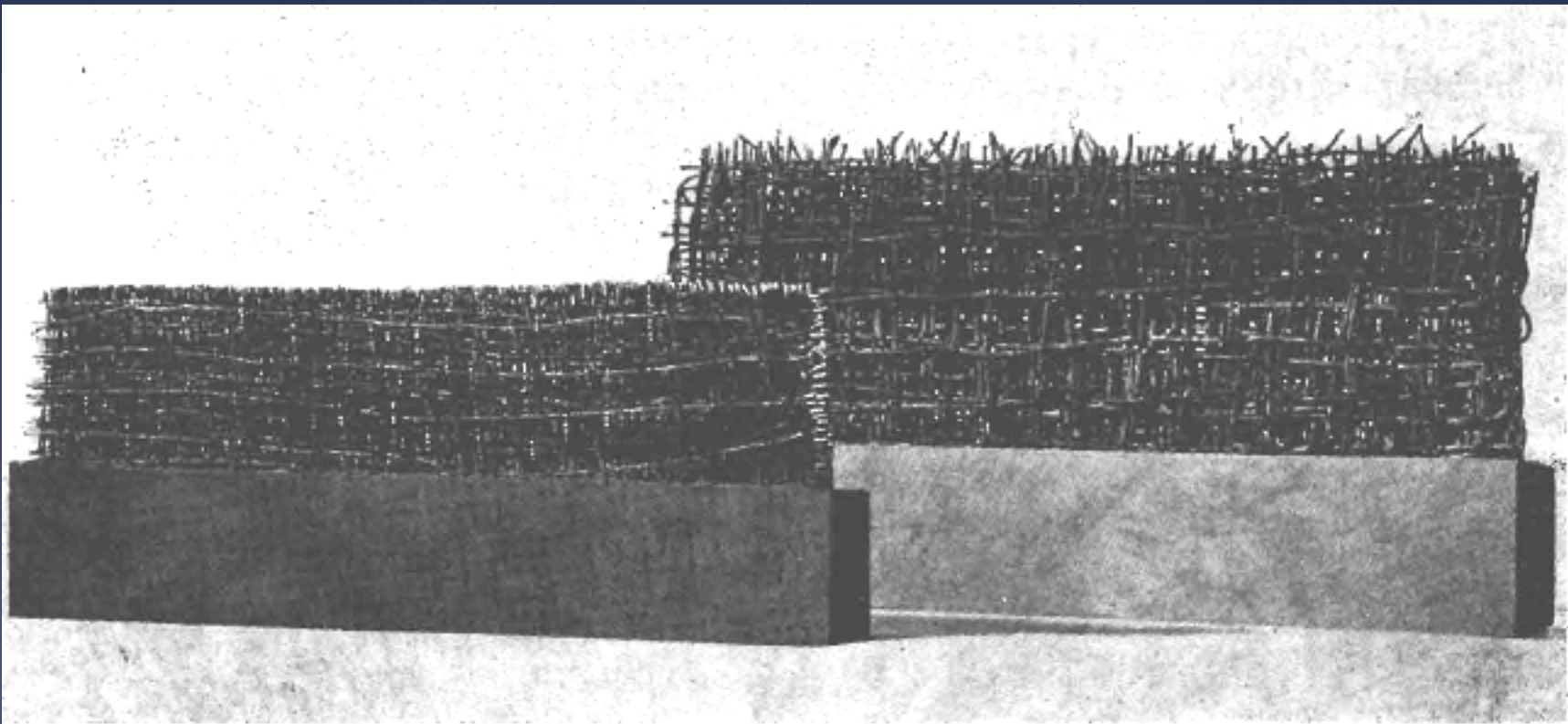
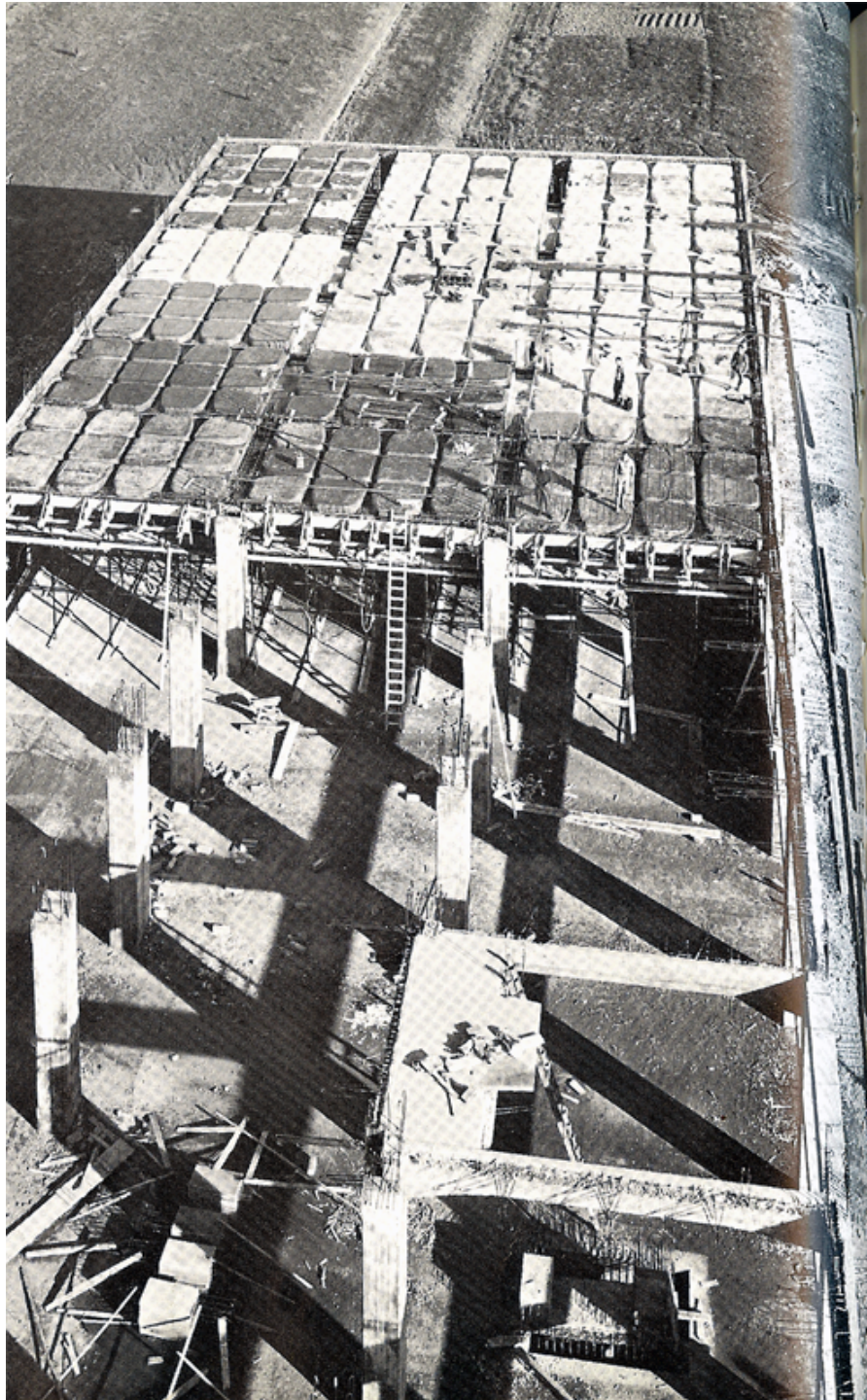
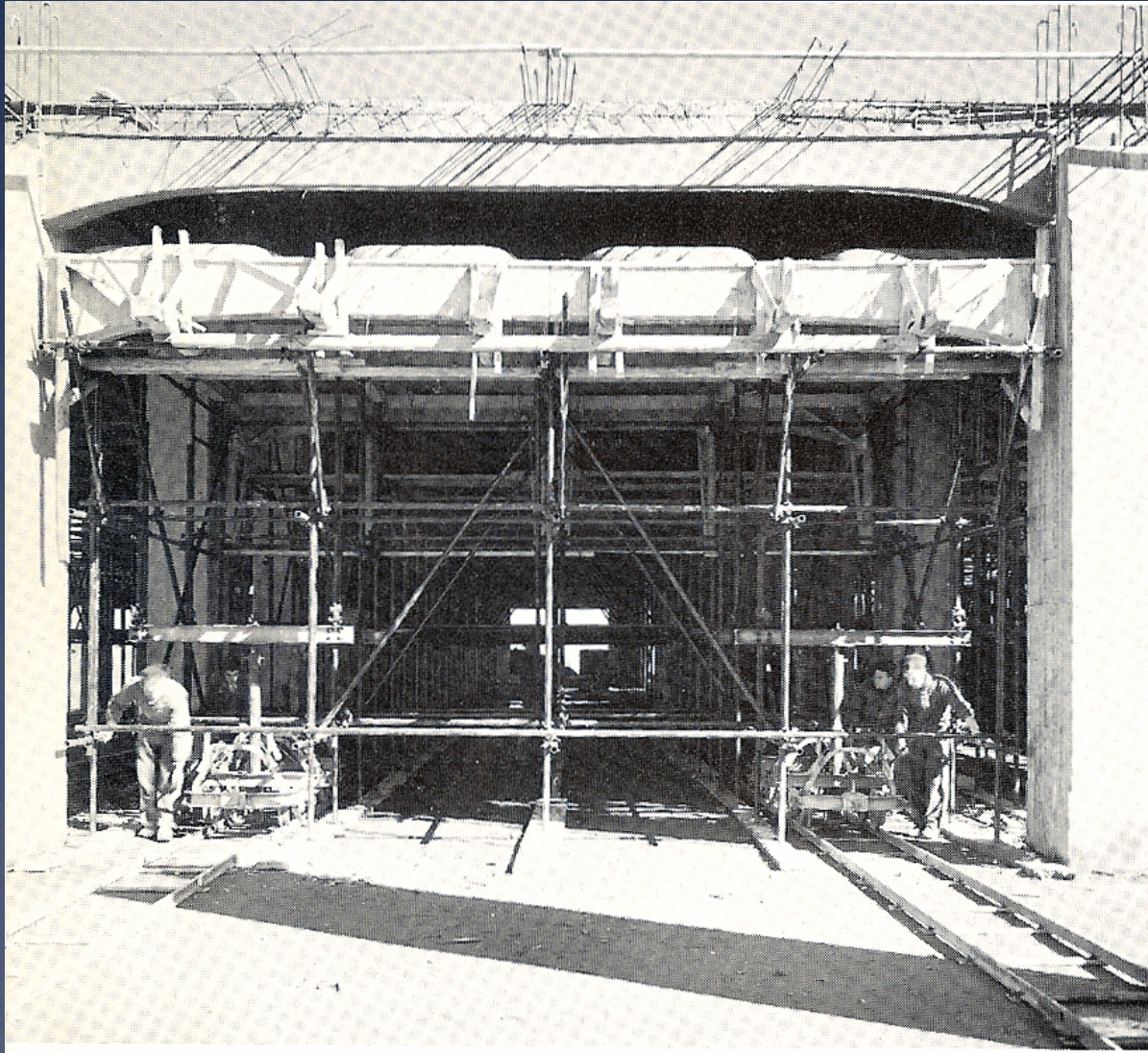


Fig.1 Thin slab samples reinforced with different layers of meshes
(taken from Nervi,1943?, cit.)



1948 Waffles & Tobacco in Bologna

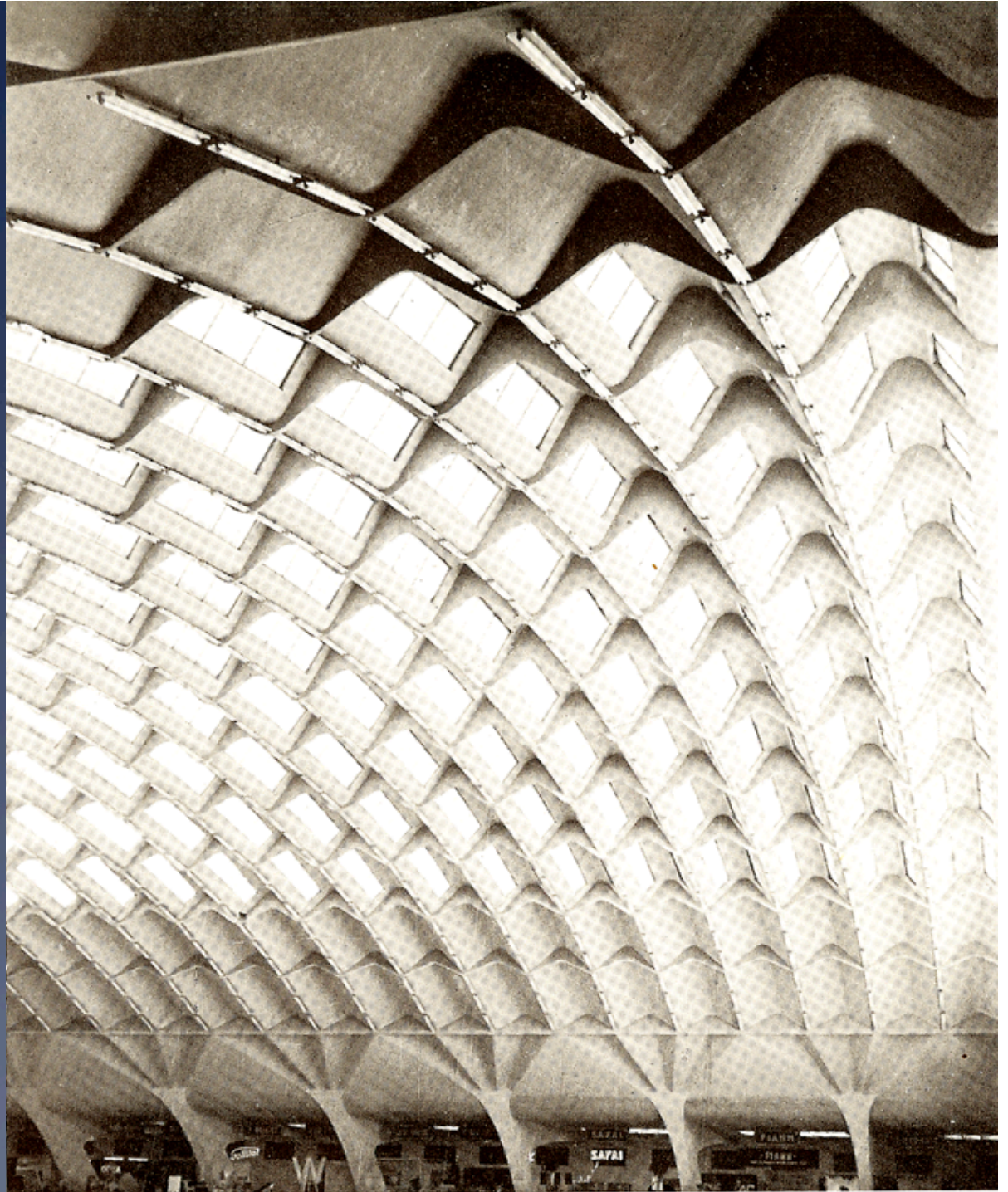
Cure, Drop & Roll

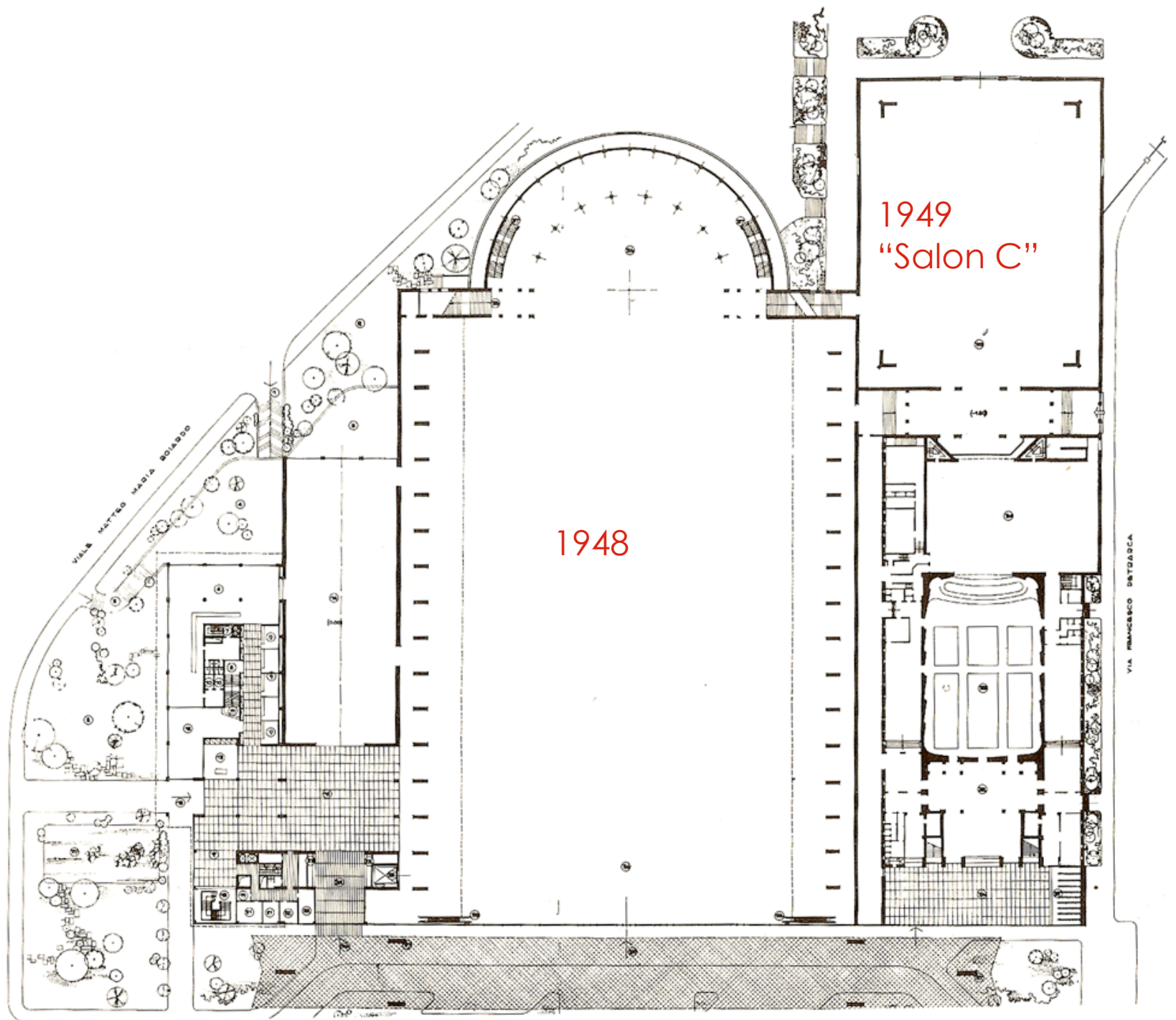




Curved
corners?

1948
Turin
Exhibition
Hall

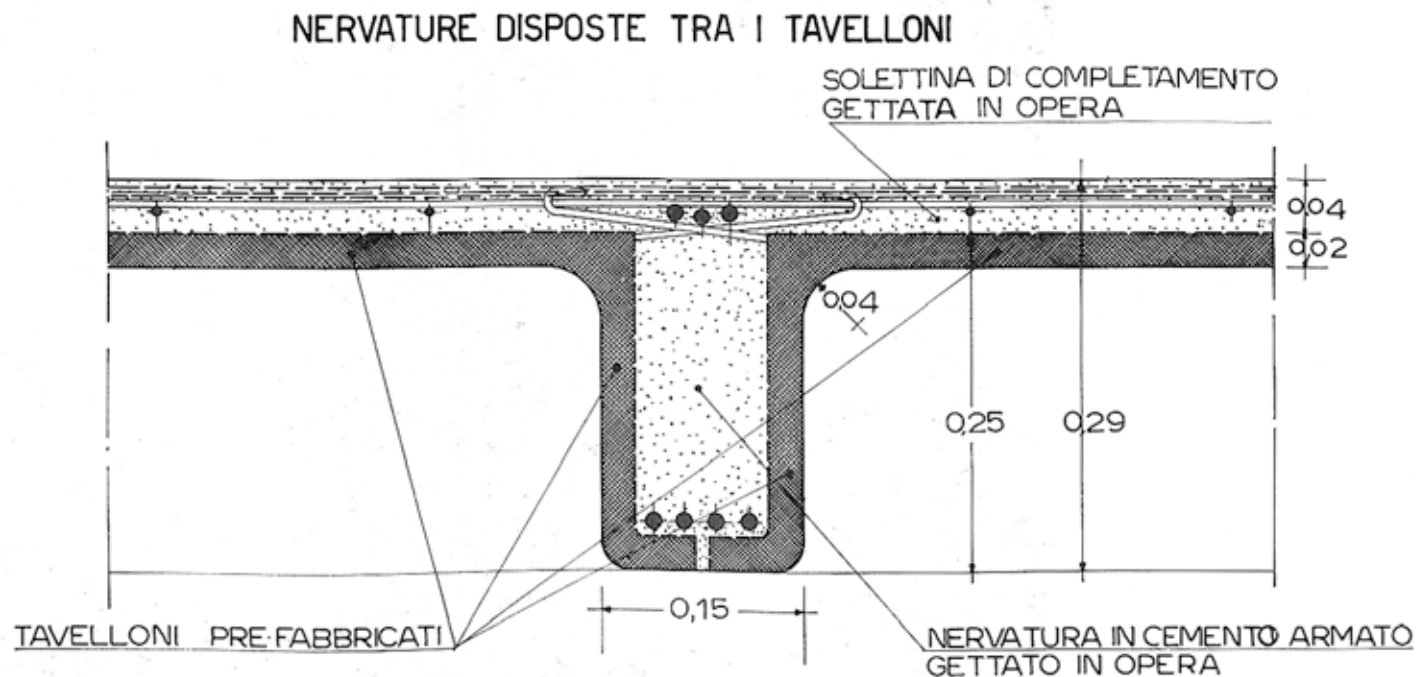




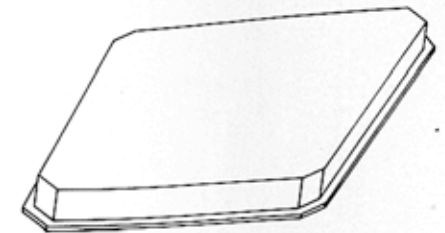


Permanent formwork

...one less operation to schedule and pay for



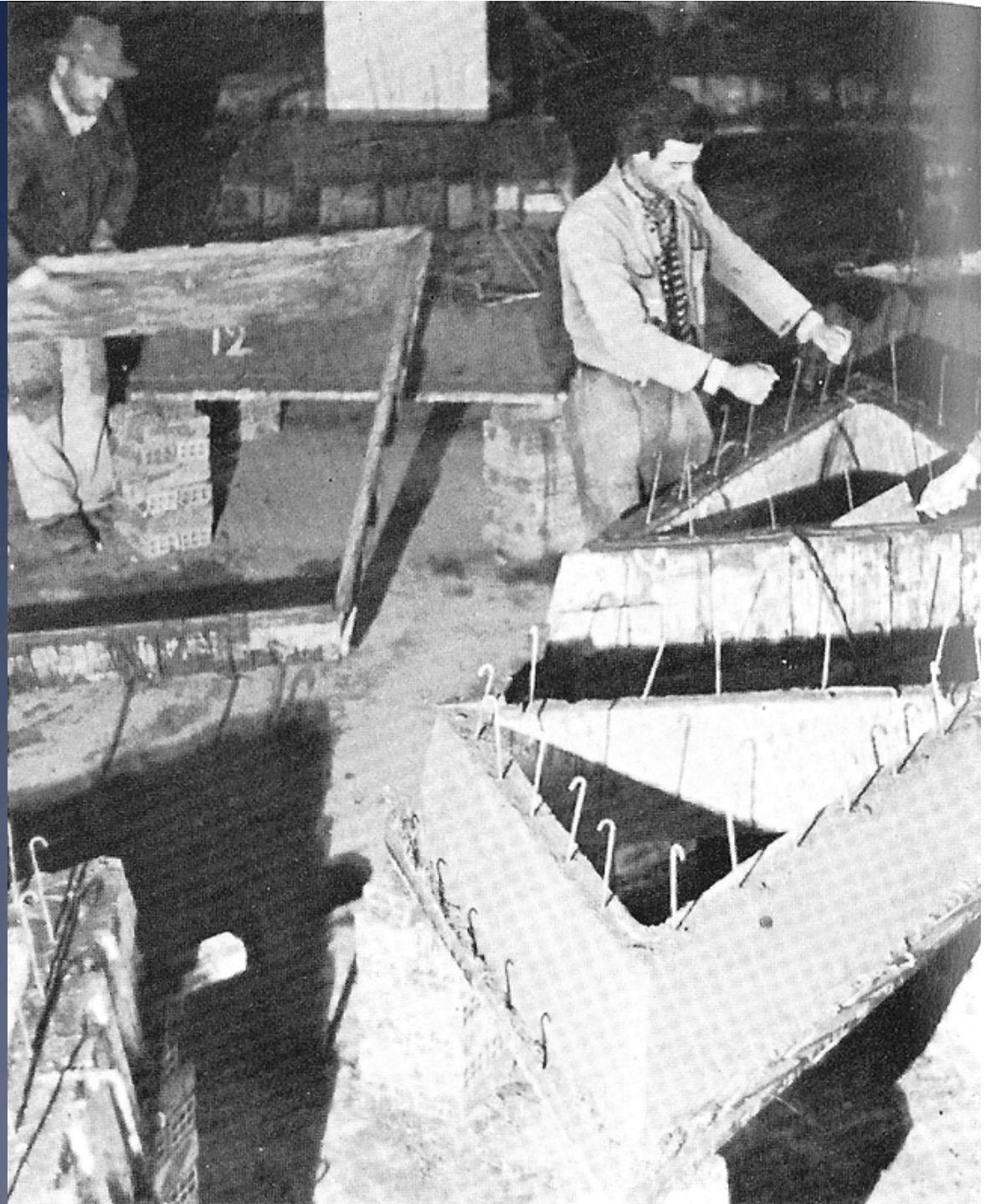
ASSONOMETRIA DI UN
TAVELLONE PREFABBRICATO





1949 "Salon C" where have we seen this before?

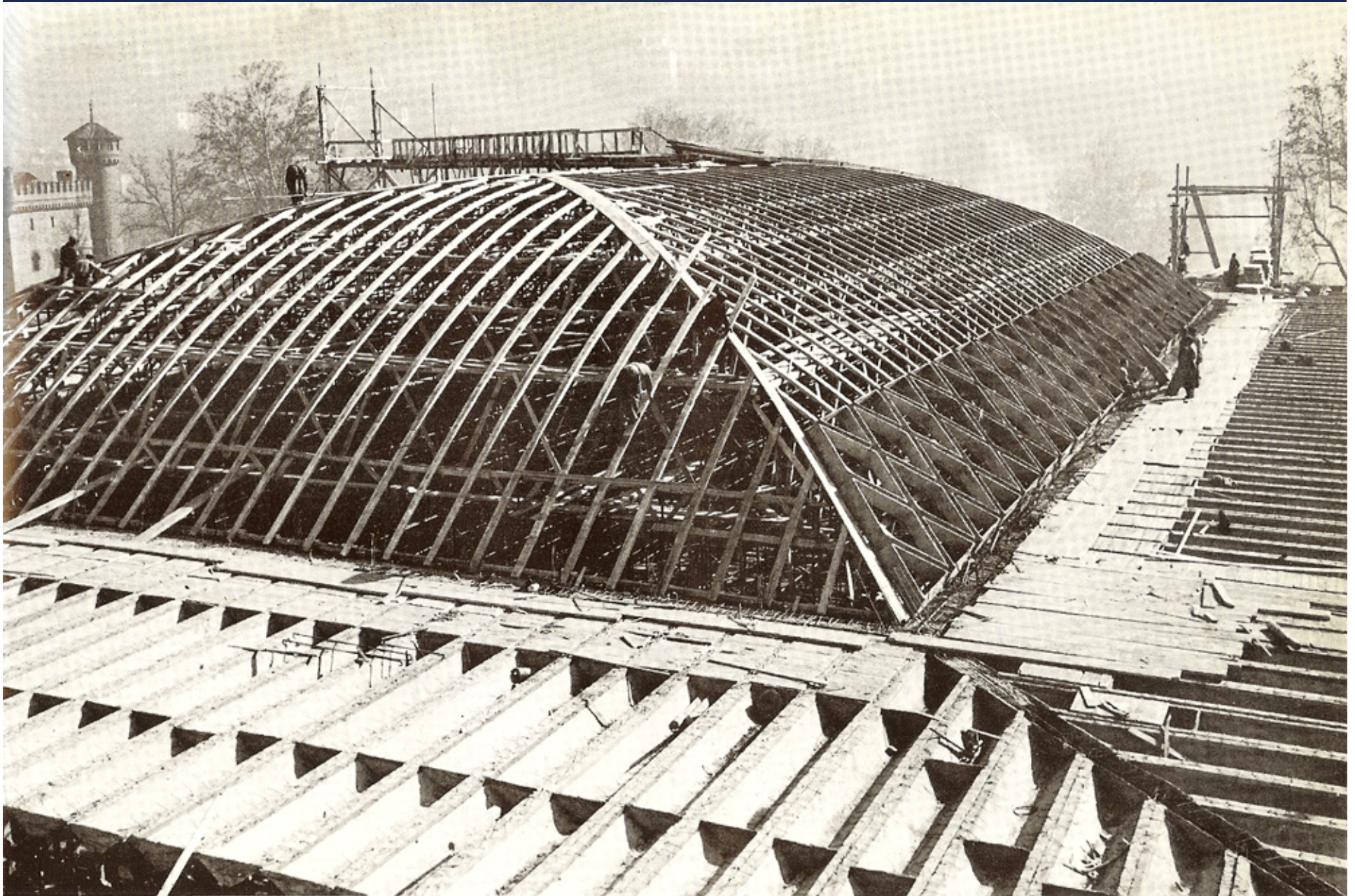
Small forms +
small steel +
small precast
parts =?



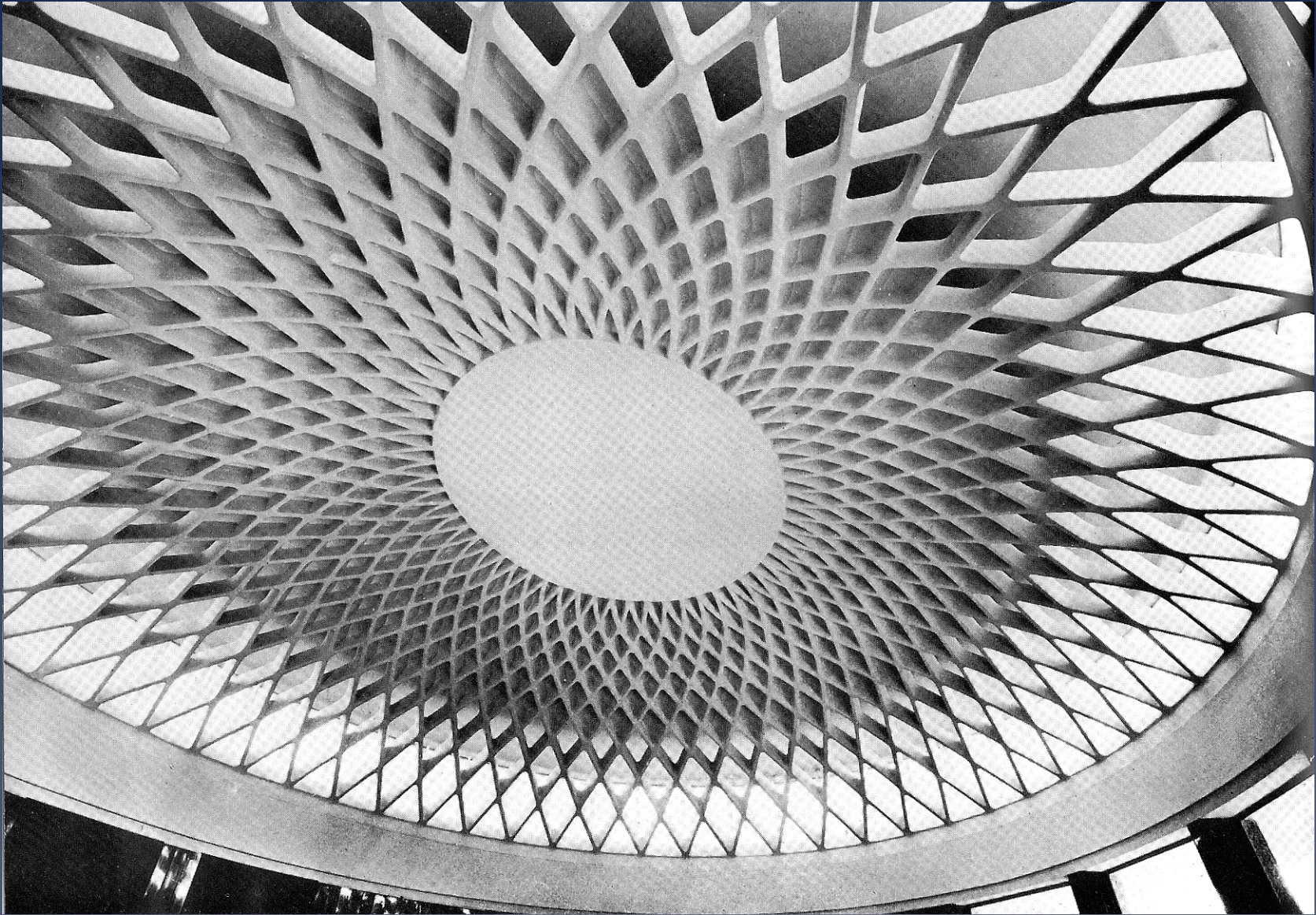
Small forms +
small steel +
small precast
parts =?



What's missing here?







1951 the return of isostatic lines Festival Hall elliptical dome

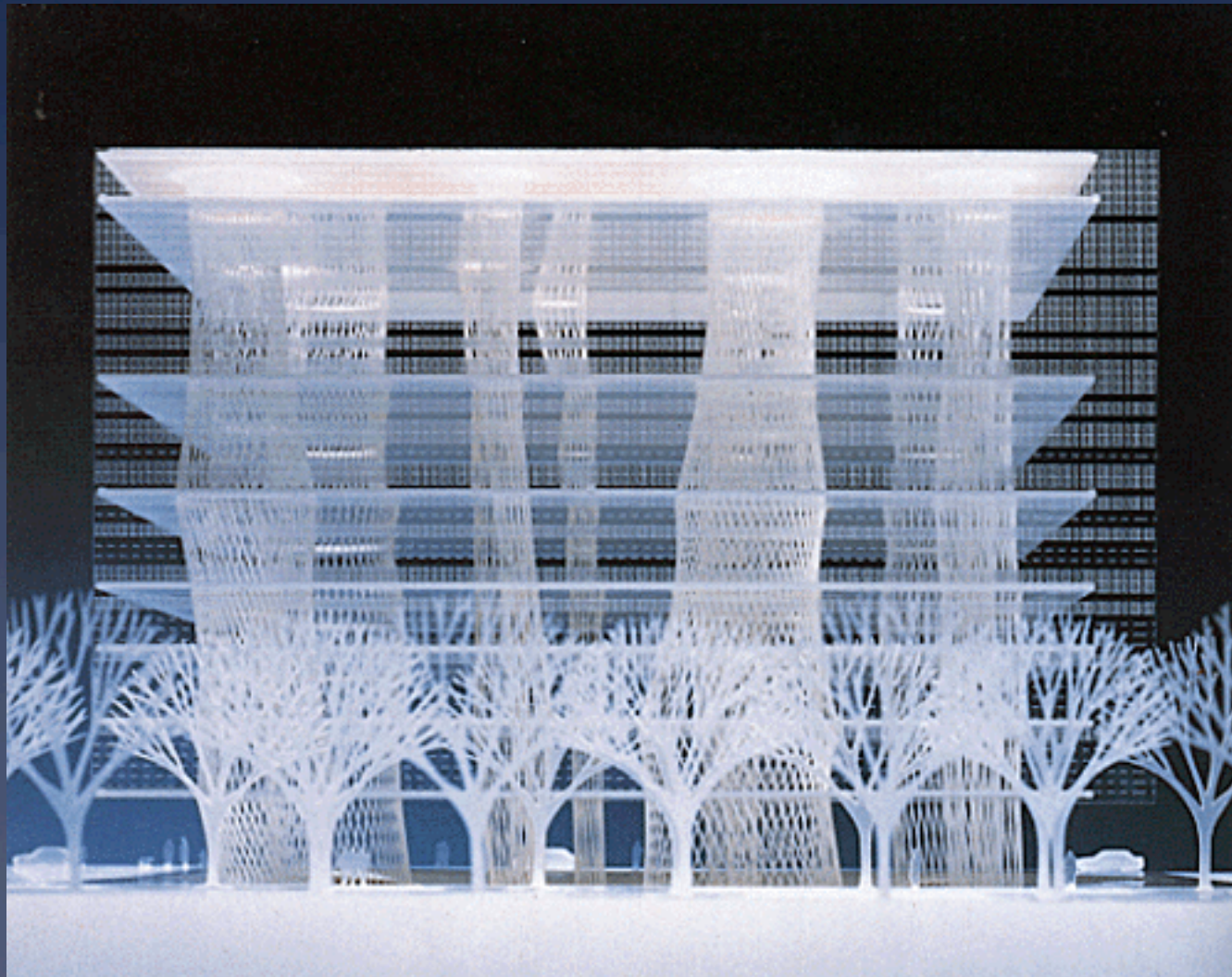
Future Lattices





Toyo Ito, TOD's shoes, Tokyo







Toyo Ito's Taichung Metropolitan Opera House Design









