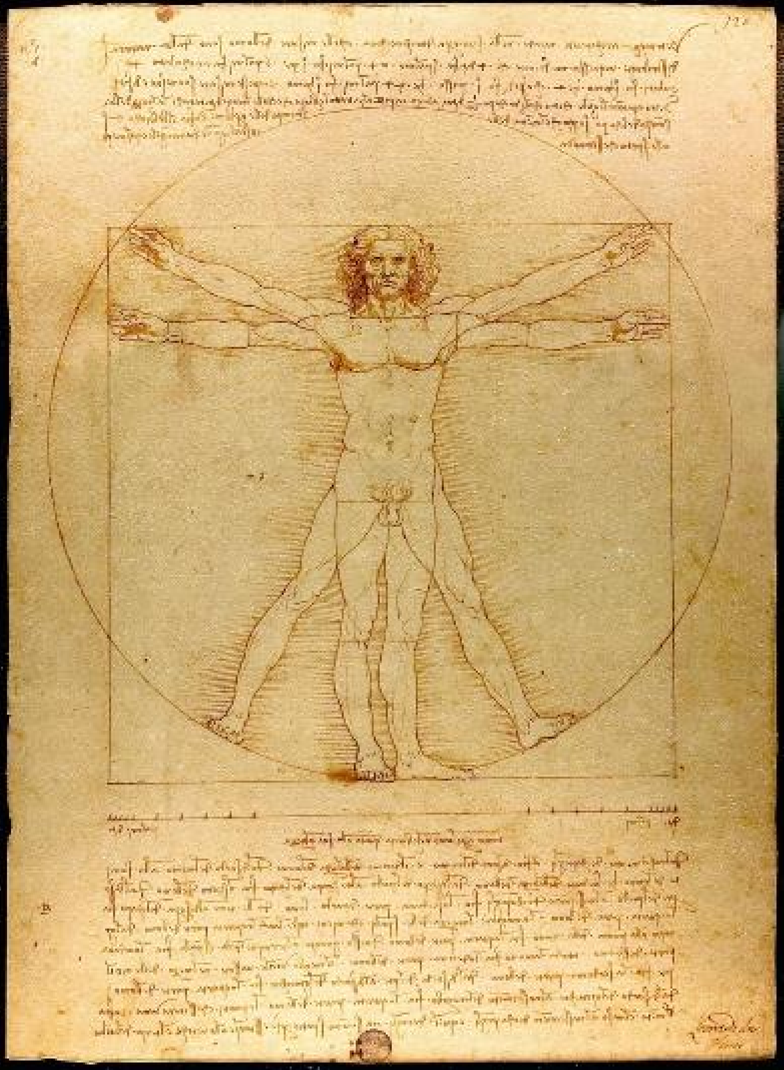
The Intrinsic Connection between Architectural Design and Structural Materiality

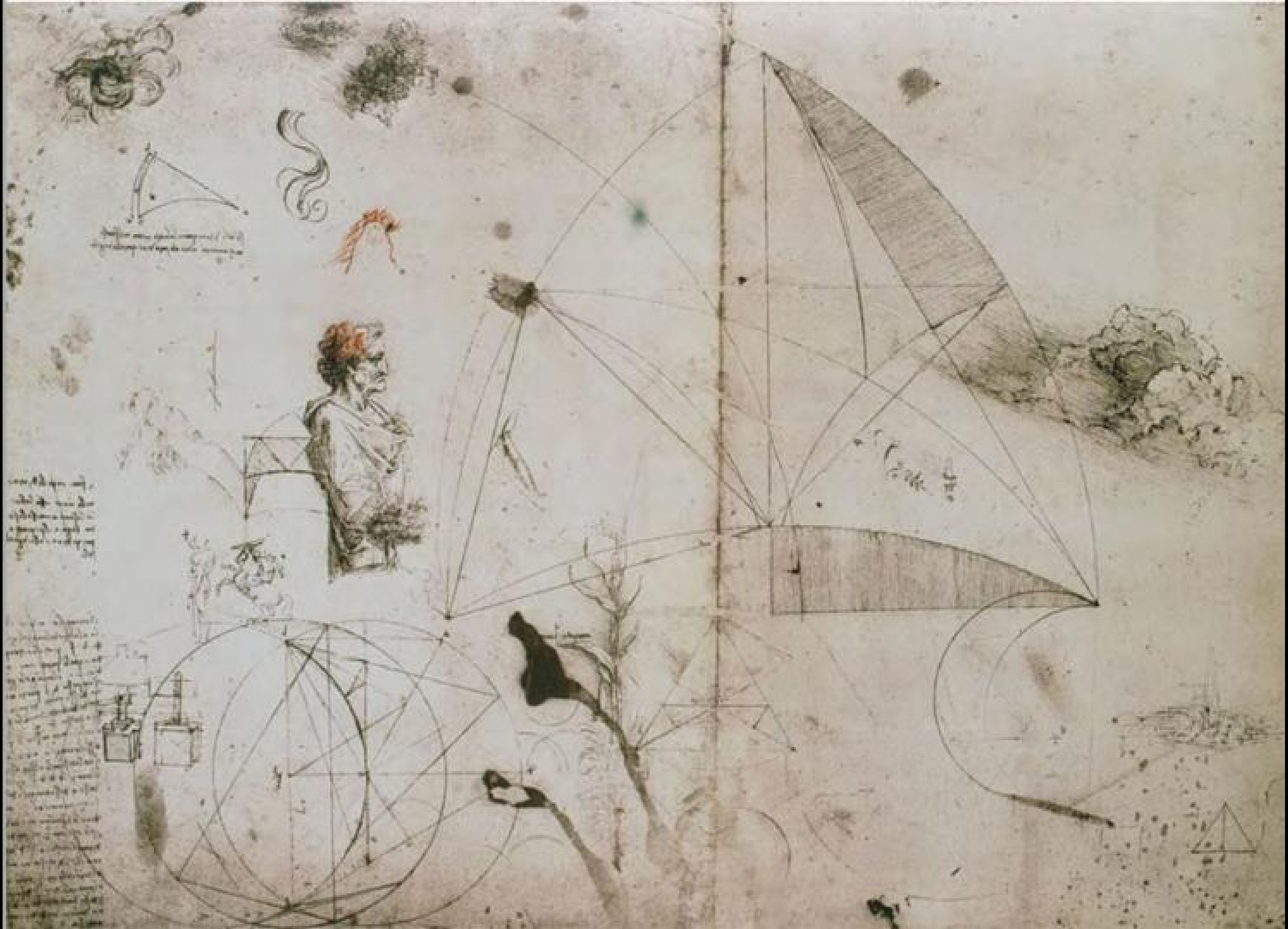
A lens for looking at….

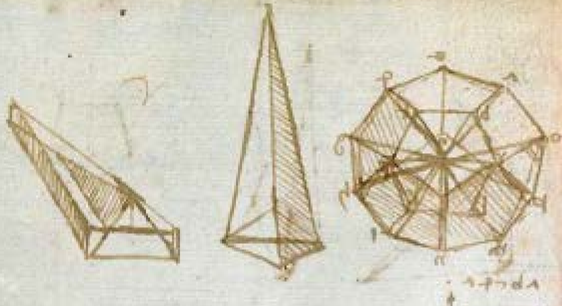
AE 101: The History of the Built Environment

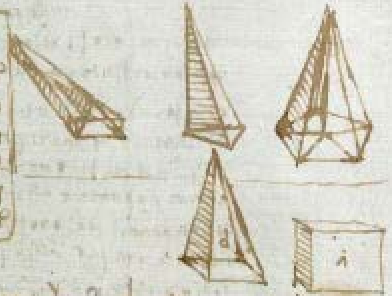
Prof. Terri Meyer Boake

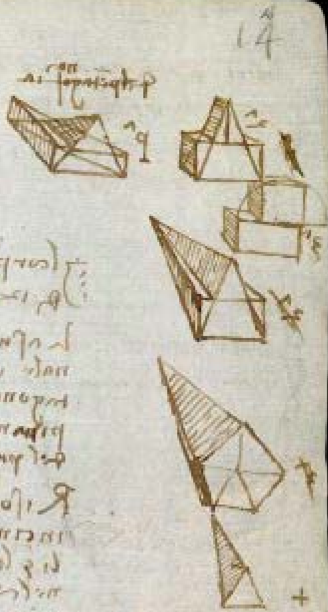


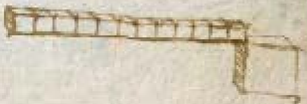
The Sketchbook



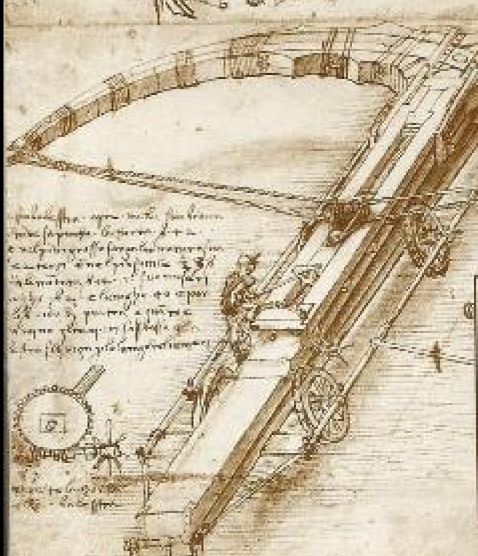






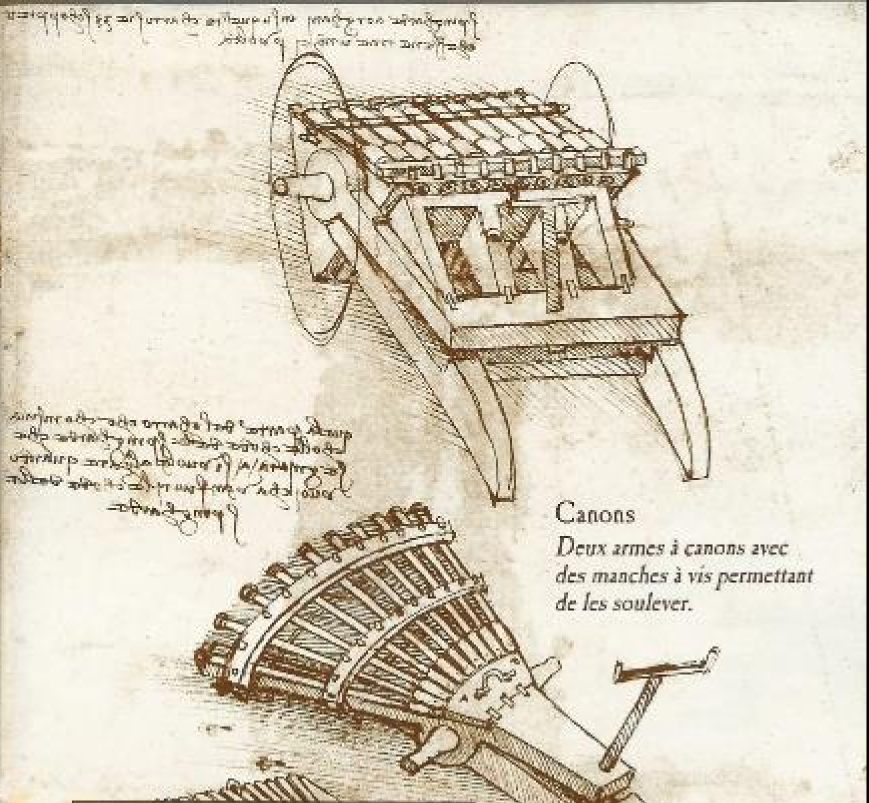


L'ingénieur militaire



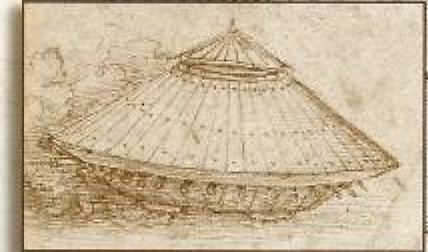
Arbalète géante

Cette arme effectuait deux actions pour tirer: un coup de marteau relâchait un ressort et un levier redressait l'arbalète.



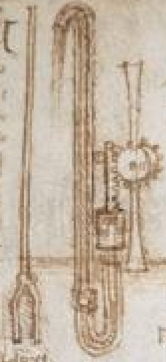
Canons

Deux armes à canons avec des manches à vis permettant de les soulever.

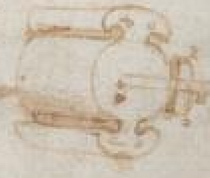


Véhicule blindé en bois

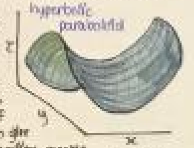
Le véhicule blindé en bois pouvait contenir jusqu'à huit personnes et était considéré comme la version mécanique d'un cavalier en armure.





- a hyperbolic paraboloid is a doubly ruled surface shaped like a saddle
- Sometimes an aesthetically satisfying shape has been sought primarily through clarity of structure, as something that can be sufficiently expressive in itself and capable also of giving a recognizable identity to a building & a sense of place to its surrounding.
- TWA Terminal at Kennedy Airport & Utzon's Sydney Opera House have a hyperbolic paraboloid shape. The wind-filled sails had to be constructed not as smooth continuous thin shells but as sets of ribs placed side by side to give a deeply corrugated cross-section capable of resisting the actions inevitably brought into play by the desired sharply pointed edges.



- multistory buildings veer toward convenience of plan and general habitability than toward aesthetics.
- the need to accommodate the increased demands of clients & unpredictable future demands have become a major constraint on the choice of structure.
- Sometime appearance is chosen almost entirely for structural reasons such as water-retaining structures & bridges.

The Development of Structural Forms

- When & where developments take place depend on many things, such local resources, fluctuations in prosperity & the objectives and priorities of those in control.

Chapter 2: Structural Actions

- To make sure a structure does not collapse, we must ensure that the active loads are balanced throughout the structure by the resistances opposed to them, that the loads passed on by the structure as a whole to the foundations are similarly balanced, that there are adequate margins of strength & stiffness under normal circumstances in all structural elements and their interconnections, and that the energy imparted by alternating loads like the wind is safely dissipated.

Loads And THEIR EFFECTS

↳ Active And Reactive Loads

- Among the normal active loads, gravitational self-weight is always present. Since it depends on the structure & the material, it's unchanging & referred to as a dead load.
- Imposed or live loads are those imposed on the structure by its user or its environment. They do change with time & they differ significantly from one another in their effect of how frequently they change, the extent of their dependence on the form & materials of the structure, and the characteristics determined by the manner of its construction. (ex: loads imposed by furniture in a room or people on a bridge)

- Within a structure there are also the loads produced by changes in temperature & humidity & even by the setting & hardening of cement when the expansions & contractions to which these tend to give rise are restrained.
- Balancing the net effects of most of these active loads at the point where the structure is supported are the normal reactive ones. The also depend on the precise manner of construction.
- Examples of reactive loads include internal air pressure

↳ Associated Movements & Deformations

- All types of load tend to produce movement in in the direction in which they act.
- The term 'stiffness' denotes the resistance that is ~~[illegible]~~ developed by a given deformation and 'strength' the maximum resistance that can be developed. Both can have different values for the same element.

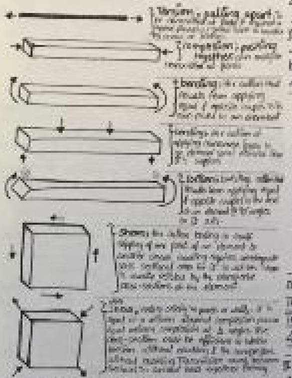
↳ Dynamic & Static Loads

- Static loads change slowly enough to allow the resistances that are developed by deformation to keep pace with them.
- Rapid changes of loads involve significant acceleration which cause inertial resistance to the mass being accelerated. Sometimes, balance is overshot.
- The amount of time a dynamic load takes to reach its peak is proportional or less than the natural period.
- Instantaneously applied loads have twice the effect of a load of the same magnitude applied slowly
- rhythmically repeated or periodic loads most damaging effects if their repetition attune in with natural vibration. A state of resonance is then encountered, with each successive application of the load reinforcing the effects of the previous application.
- Static loads are the most important ones for most buildings.
- Dynamic & periodic loads of comparable magnitude are usually of special & infrequent occurrence
- The commonest dynamic load is wind. The external form & orientation of the structure should minimize the pressure on different faces.
- noticeable dynamic effects are usually confined to structures with long natural periods of vibrations. (ex: tall slender buildings, chimney stacks...)
The effects can be greatly magnified by [illegible] of the cross-section to one that leads to a regular formation & shedding of vortices roughly in step with the natural vibrations.
- dynamic loads due to earthquakes are less common. they are inertial loads acting on all parts of a structure when the ground as a result of very rapid displacements of its foundations. they depend on the mass of the structure & vibrations of the whole structure & its elements, on whether they respond by bending, rocking, and ability to dissipate energy.

Internal Actions

↳ Tension, compression, bending torsion, & shear

- A single force is represented by a straight arrow and a pair of equal & opposite parallel forces, that tend to cause rotations, by a curved arrow.



- Each type of action may also occur at joints between elements.
- Elements with large cross-section areas are required to resist bending or torsion
- Appreciable cross-section areas are required to resist compression because any departure from axiality in the load will result in bending that will increase the non-axiality & may lead to buckling.
- Non-axial tensile load tends to realign the element with the load rather than smaller cross-section areas are adequate.
- ~~[illegible]~~ Transmission of bending requires a joint that resist compression, tension, & shear (and torsion forces) (ex: welded joint)

↳ Actions of Human Frame

- Skeleton resist compression & a limited amount of bending. Tension is taken by the ligaments & muscles.
- Rotation of joints depend on the friction between them. Thus, they are capable of transmitting compression & some tension and shear & limited amounts of bending and rotation when no further rotation is allowed.
- bending [illegible] are required by the whole frame
- To maintain static balance, the body either adjust the stance or adjust the magnitude of the internal tension & compression.

↳ Actions of the Built Structure

- All subsequent behaviour depends on external circumstances.
- Humans can't easily tell all the structure respond.

Structural Requirements

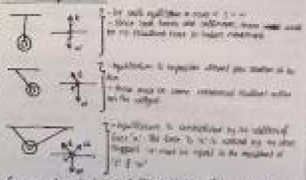
↳ The Basic Geometric Requirement

- In order to form all basic systems & not fall a loose assemblage, the elements must be [illegible] joined to a 3-D space enclosed by the structure & for the flow of all likely loads.

↳ The Complementary Needs for Adequate Strength & Stiffness

- If the geometric requirement is satisfied, the individual elements & joints should have the requisite strength & stiffness.
- In complex structures the nature of the elements is determined by exploring the balance of the forces @ work - static equilibrium

↳ Static Equilibrium

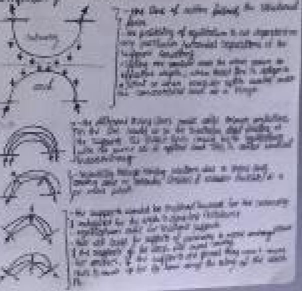


- For a system to be in static equilibrium, it must have a zero linear resultant in every direction, & have no resultant moment.

The Equilibrium of Some Structural Elements Acting in Simple Tension or Compression

↳ The Catenary & The Arch

- Both are uniaxial structures. The arch would fall to the ground if inverted & the catenary would merely change its shape to the opposite. [illegible] is self-equilibrating unless the moment which is cat. [illegible] is overcome by an appreciable depth to the structure & [illegible] loading.
- Since [illegible] [illegible] any arches differ, it may [illegible] if the [illegible] of the [illegible] of the joints coupled with relative slip of some of the [illegible].
- The [illegible] internal forces will be distributed over the [illegible] [illegible] of the cross-section of either the catenary or the arch, and will be [illegible] [illegible] to simple concentrated tensions or compressions.



Stone: From Technique to Technology

- early in history, 'trial and error' was the way to build

Aesthetics

- a branch of philosophy that explores the nature of art, beauty, and taste, with creation and appreciation of beauty

Stone:

- natural material
- great for compression
- some stones are better for constructions e.g. sandstone is very brittle/erodes easily
- stone gets destroyed by pigeons
- water imparts materials, moss and lichens can also deteriorate

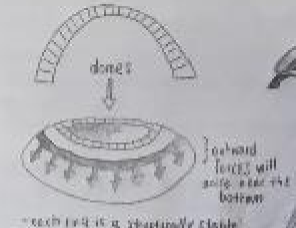
Forces

- tension i.e. stretching
- compression i.e. crushing
- moment/torque i.e. bending

Using the ARCH to Span

Gothic Arch

- better fits the ideal line of pressure
- if the top was too high, sides will fall inwards



- each ring is a structurally stable compression ring
- bursting forces can be countered by buttresses or mass from a ring below

Technique vs Technology

- trial and error vs. mathematics and physics

Stonehenge

3000 B.C.E, Wiltshire, England

- historians not sure how it was built
- sundials, clocks, advanced stone placement

Law of Hammurabai

1750 B.C.E.

- basically, if a builder built a house and that building fell and killed someone, the builder would be put to death

Ancient Stone Techniques

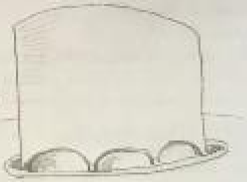
Egypt: used ramps to move heavy objects (stones)

Stepped Pyramid of Djoser at Saqqara (27th Century B.C.E.)

- surroundings currently in bad repair
- tough times to restore because sandstone is eroding

MIT Chapel
Cambridge, Massachusetts (1955)
Eero Saarinen

- cylinder
- modern movement, very simple
- little arches along bottom
- moat along bottom that reflects light into the chapel
- solid masonry walls
- skylight over raised pedestal, "sparkles" overtop
- interior brick design pattern is different from exterior



MIT Chapel

Rothko Chapel
Houston, Texas (1971)
Philip Johnson

- extremely simple and reflective of modern movement
- drawing visitors; flat roof made skylighting

Philips Exeter Academy Library
Exeter, New Hampshire (1972)
Louis I. Khan

- modern, regular plan, "formalist", symmetrical
- ... in the design
- exterior is brick, interior ... concrete
- large open space + galleries

Philips Exeter Library

Palmer Museum of Art
Penn State University, State College, Pennsylvania (1990)
Charles W. Moore

- "post modern"
- revival of classical architecture known as ...
- arches, ..., colors (common on ... and ...)
- symmetry was important
- worked with w/ masonry (small brick units are adaptable to different shapes in structures)

Brown College
Rice University, Houston, Texas (2002)
Michael Graves

- masonry, ... coursing
- decorative brick laying
- flat mortar joints ... less ...
- wooden arches to support ceiling
  - ... Residence building ...; same style with brick

Herring Hall
Rice University, Houston, Texas (1984)
Cesar Pelli, Architect

- "post modern"
- ... made of ... (specially manufactured)
- ... brick pattern
- ...
- ...
- ...

Anne and Charles Duncan Hall
Rice University, Houston, Texas (1996)
John Outram Associates

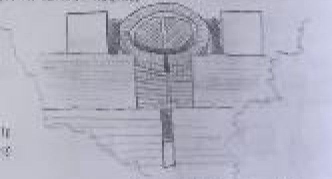
- arches, capitals
- exquisite brick detailing, some are glazed
- colorful interior (...)
- byzantine mosaic ceiling

From a stylistic perspective brick has invited an eclectic attitude towards styles and revivalism

Brick can be made as large precast panels and hung from the building to make a ... at height in ... weather

Museum of Modern Art
San Francisco, California (1995)
Mario Botta

- ..., square windows, simplified
- "Stripy"
- fairly symmetrical
- ..., brick panels
- ... done in brick ...



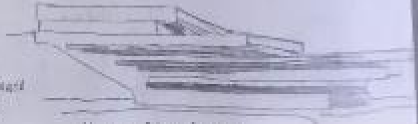
Museum of Modern Art

Millennium Science Complex
Penn State University, State College, Pennsylvania (2011)
Rafael Viñoly Architects

- massive cantilevers
- brick panels that were prefabricated; construction process easier
- special ... in the underside

Dr. Chau Chak Wing Building
Sydney, Australia (2015)
Frank Gehry

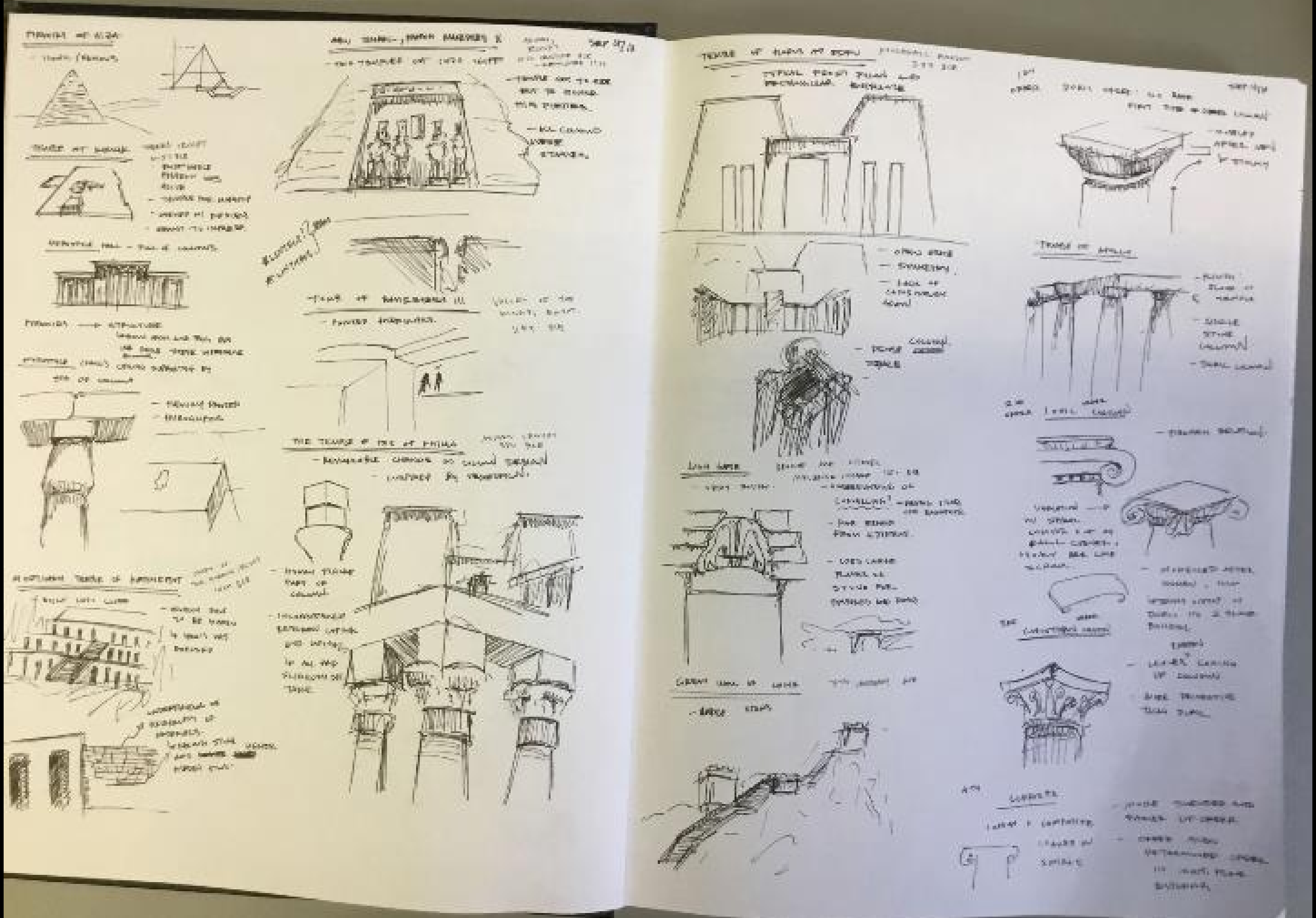
- odd angles ... to ...
- custom prefabricated brick panels



Millennium Science Complex

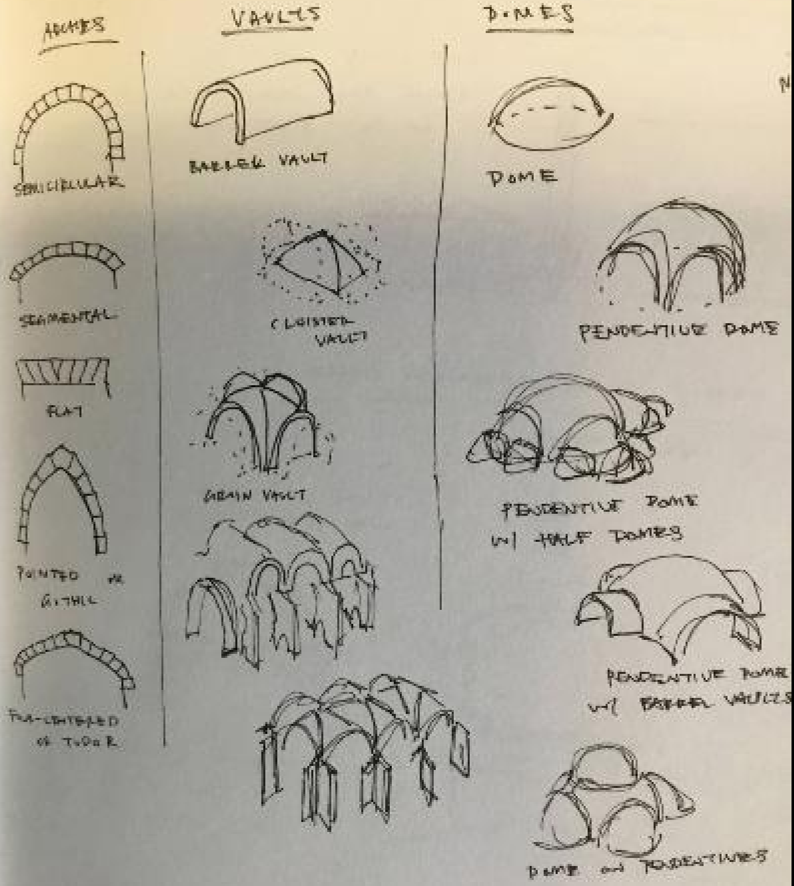

HAGIA SOPHIA


ST. MARK'S BASILICA


LION GATE
TEMPLE OF APOLLO
COMPOSITE

THE RENAISSANCE
ROUEN CATHEDRAL
ROUEN, FRANCE
WESTMINSTER ABBEY

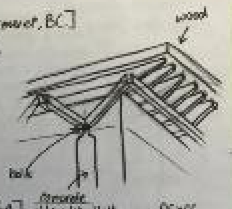
ch 17:

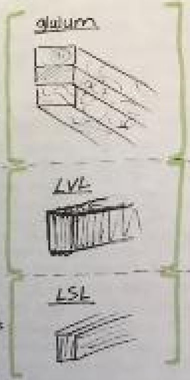


Glulam (glue laminated timber)
↳ fabricated by gluing individual pieces of dimensional lumber together to form columns, beams, & headers.
↳ can be made out of young trees
↳ glue-laminated timber panels have the appearance of glulam beams laid flat. These pane[ls] provide a strong & economical flooring option with one-way spanning capability.

- Laminated Veneer Lumber (LVL)
↳ fabricated by laminating & gluing multiple veneers together in the same orientation. This enabl[es] long elements to be produced that have high strength in one direction.

- Laminated Strand Lumber (LSL)
↳ fabricated from flaked wood strands glued together in large billets. The length is limited only by standard shipping & trucking dimentions. (strands usually 3mm thick & 2.4mm long & not very wide)
↳ LSL can be used for floors, walls, & vertical members where large floor-to-floor heights are required (used for beams/column)

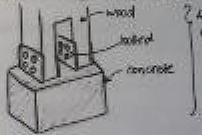




Canada
- Stanley Park (~~[illegible]~~ Visitor Center) - [Vancouver, BC]
↳ government buildings MUST use wood (law)
↳ beams are spanning at 90° angles
↳ use bolts in heavy timber
↳ steel hidden inside

USA
- Holt Center for the Performing Arts [Oregon, USA] - Hardy Holzman Pfeiffer Associates HHPA
↳ can see cracks on wood
↳ architect wanted it to look like a forest.
↳ want to conceal that steel that is holding everything together

- Pierre H. Kruger Pavilion Laval University [Quebec] - Paul Gauthier + Guillaume Hudon Architects 2008



↳ how to connect wood to foundation

△ How do you curve glulam?
If it's heavy enough, it does it by itself

Canada
- Jackson-Triggs Niagara Estate Winery [Niagara-on-the-Lake, Ontario] - KPMB Architect 2001
↳ steel & timber
↳ steel joists, corrugated decking, steel plates in wooden beam
↳ windows not at eyelevel
- Scarborough Civic Center Library [Scarborough, ON] - LGA Architectural Partners & Phillip H Carter Architects
↳ wood goes through glass
↳ exposed bolts
- Richmond City Hall [Richmond, BC] - KPMB Architect with Hotson Bakker 2000
↳ crossover pattern
- Travel Terminal [Hakurin, Japan]

BC → trees are in the ro[ad] but it's not getting rid[] through because of global warming.

CHINA - GREECE

- [illegible]
  - inside painted as frescoes
- [illegible]
  - multiple columns + designs
  - inspired by vegetation
  - size limited by ability of material to span
  - all temples had a different [illegible] individuality?
- [illegible] at [illegible], 1[illegible] BCE
  - formalized open space
  - surrounded by columns (courtyard)
  - symmetry of space
  - allows light to enter
  - space is [illegible] no. of columns
- [illegible], 1[illegible] BCE
  - limestone
  - smoother lines
  - fortification (thick)
  - corbeling (support structure like an arch or balcony)
- [illegible] 7th century BCE
  - [illegible] + stone

- Order of columns → DORIC order
  - columns → [illegible] different visibly in Egypt
  - similar [illegible] temple
  - reflecting off human body

- [illegible]
  - columns carved in one piece
  - Greeks + added mathematics into their art
- [illegible] circa [illegible] BCE
- [illegible] [illegible] BCE
  - [illegible] capitals
  - colonnade around perimeter
- [illegible] Athens
  - [illegible] columns, carved as women to hold up porch
- [illegible] (Greece)
  - [illegible] columns, mainly
- [illegible] (Italy)
  - typical temple architecture
- [illegible] 4[illegible] BCE
  - style of architecture more refined

- the classical style → used round arches

key characteristic of Roman construction

generally developed after steel columns + reinforced concrete became [illegible]

- [illegible]
  - promenade
  - around arches
- [illegible] Italy
  - walls plastered over
  - originally coloured

[illegible] Building: [illegible]

① THE OUTDOOR ENVIRONMENT

The Earth and the Sun

- Sun is an important factor in the lives of people and buildings
  - warms body + buildings by direct radiation or warming the surroundings
  - illuminates outdoors, disinfects surfaces, produces vitamin D
- Sun is both a giver of life + destroyer
  - disintegrates materials, burns, promotes skin cancer
- sunlight includes electromagnetic radiation
- Earth is closest to the sun in winter, so the orbital eccentricity helps to slightly moderate seasons
- seasons created by tilt between axis of Earth's rotation + a perpendicular to the plane of its orbit

The Equinoxes

- March and September 21
  - vernal equinox
  - autumnal equinox
- North and South pole are equidistant from the sun
- Sun rises and sets exactly [illegible] except at extreme poles — sun travels along horizon for 24 hrs

The Annual Cycle

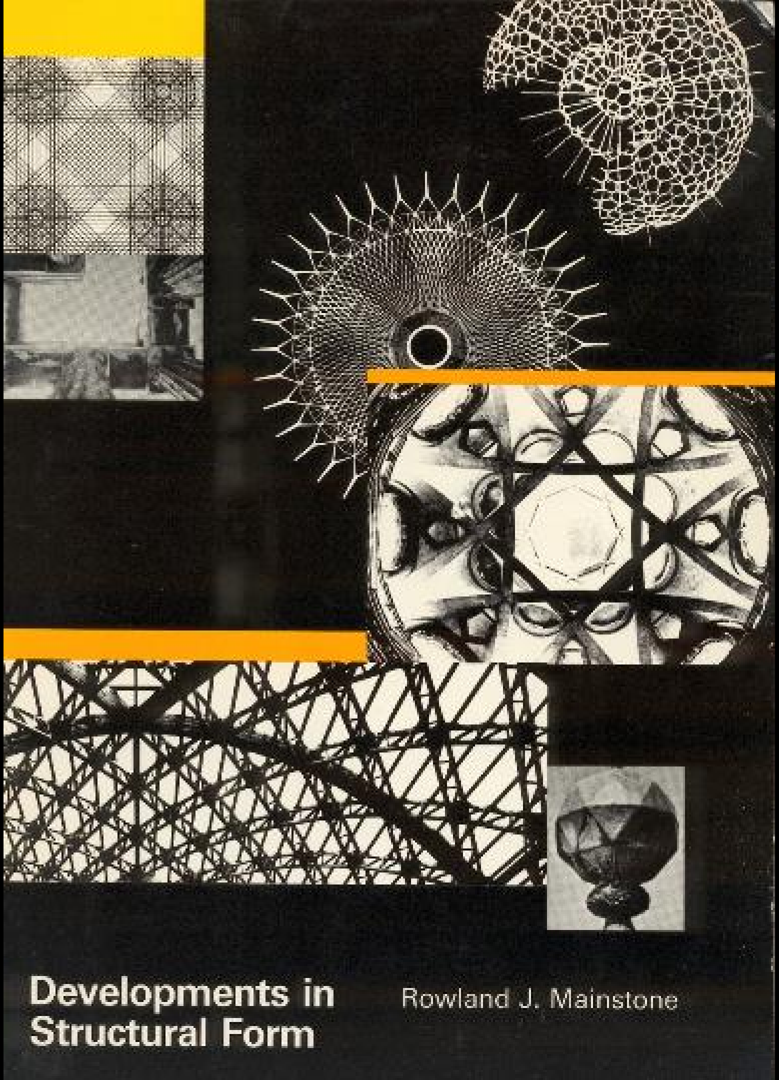
- over the course of a year, every point on the globe is exposed to direct sunlight roughly half the time
- @ the poles, this portion of sunlight comes in one continuous 6-month period
- @ the equator, each day of the year is evenly divided between daylight and darkness
- @ intermediate latitudes, longer summer days compensate for shorter ones in winter

The Summer Solstice

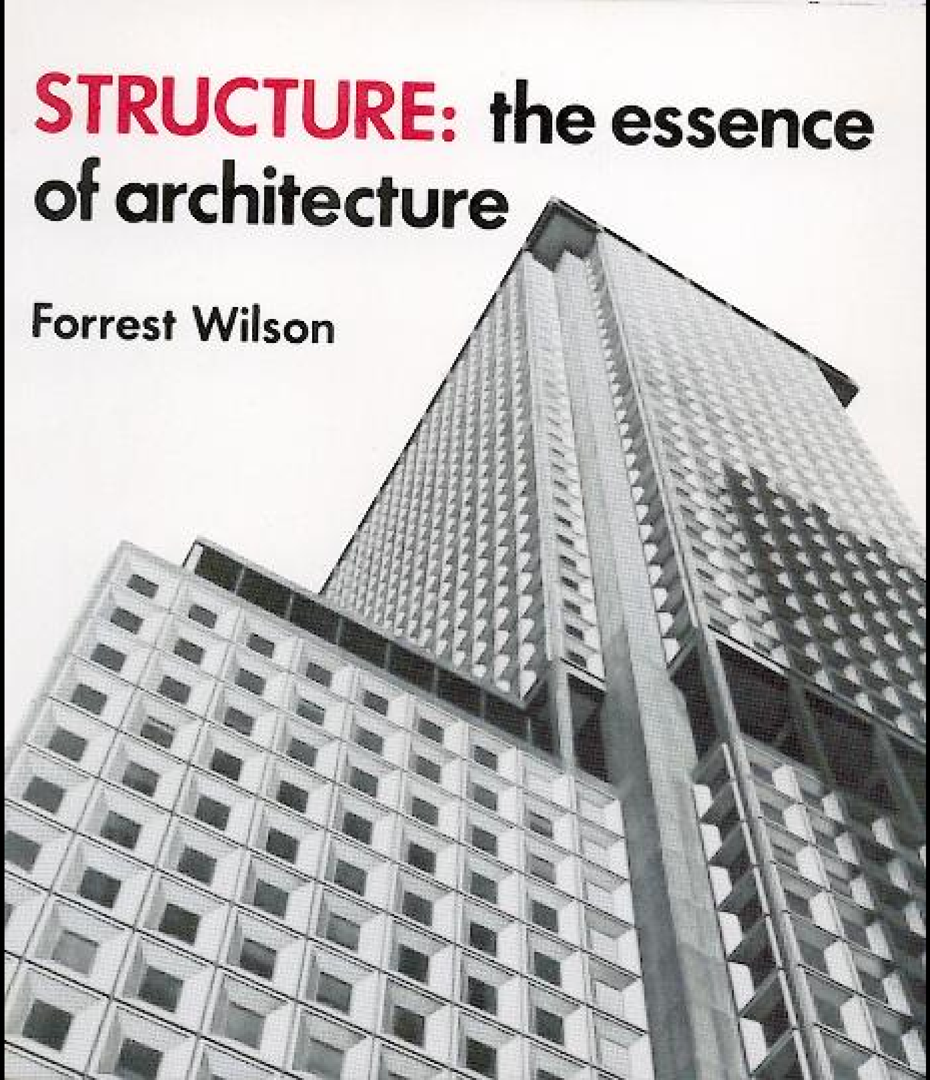
- occurs when the sun rays are at their farthest at an orbital position (normally around June 21)
- the sun is seen for a longer period of time on this day than other days
- hottest season occurs later since land + water hold considerable solar heat during warmer days
- later, Earth gives back the stored energy to cooler air (moderating the effect)
- winter solstice - opposite (Dec 21)
  - fewest hours of sunlight

Effects of Solar Radiation on Earth

- length of day
- angle of incidence of sunlight on the ground at each time of day
- amount of atmosphere [illegible] by the radiation at each time of day



Developments in
Structural Form
Rowland J. Mainstone

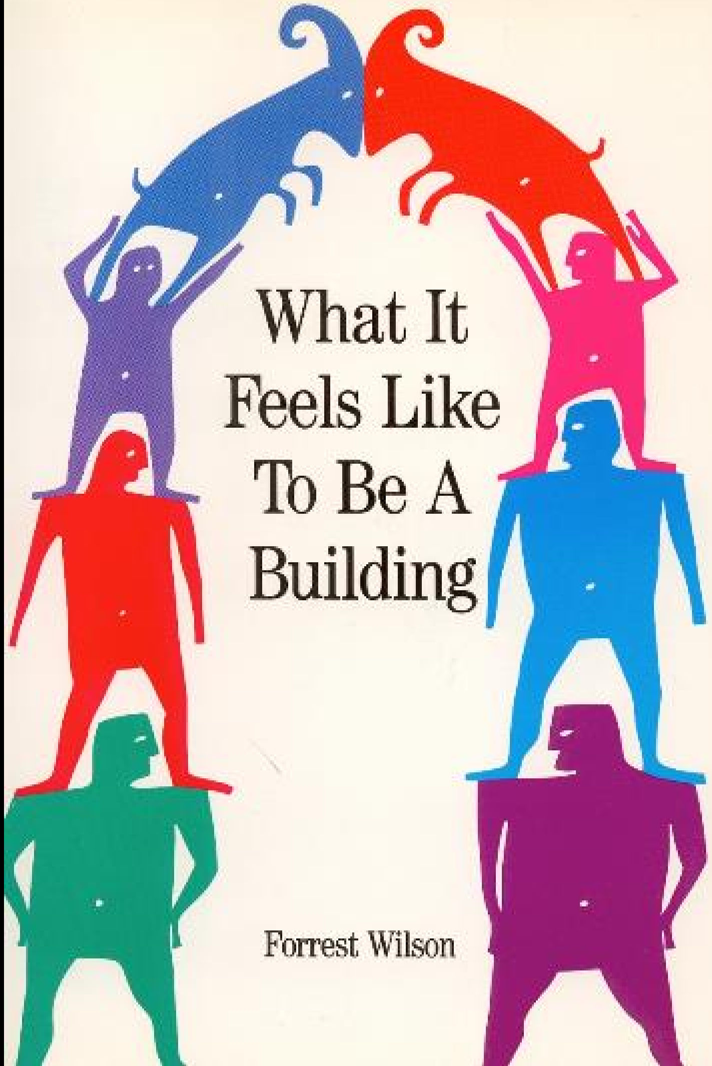


STRUCTURE: the essence
of architecture
Forrest Wilson

forces

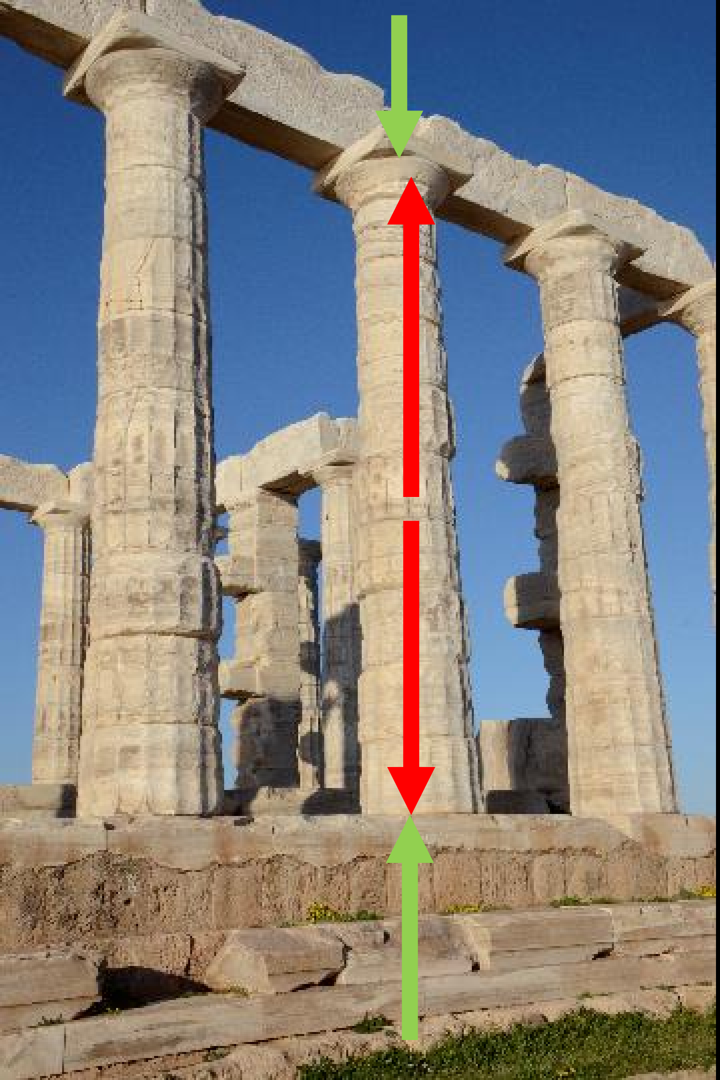
Some materials are better than others at resisting forces

We can make better design choices if we select the materials that are better for the job



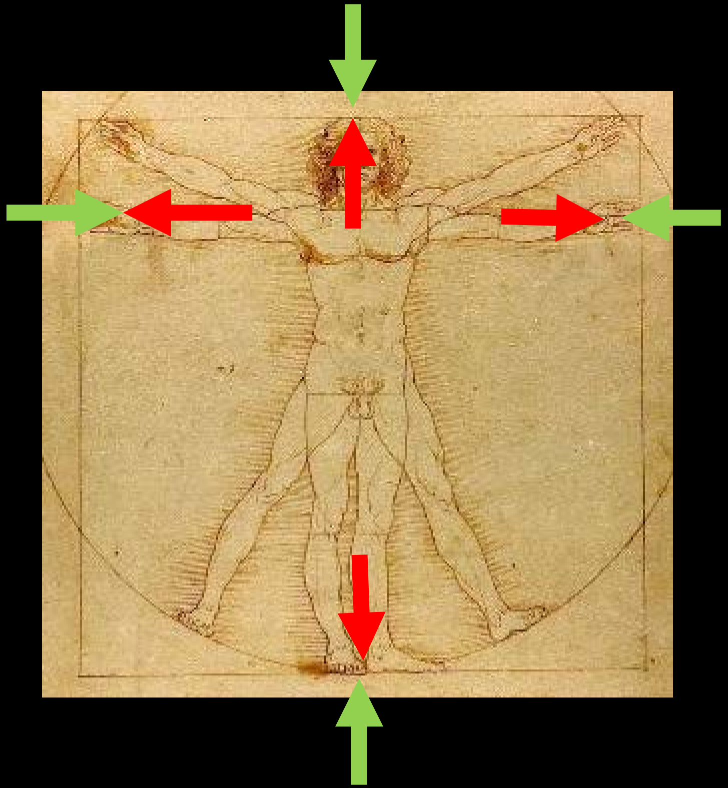
What It Feels Like To Be A Building

Forrest Wilson



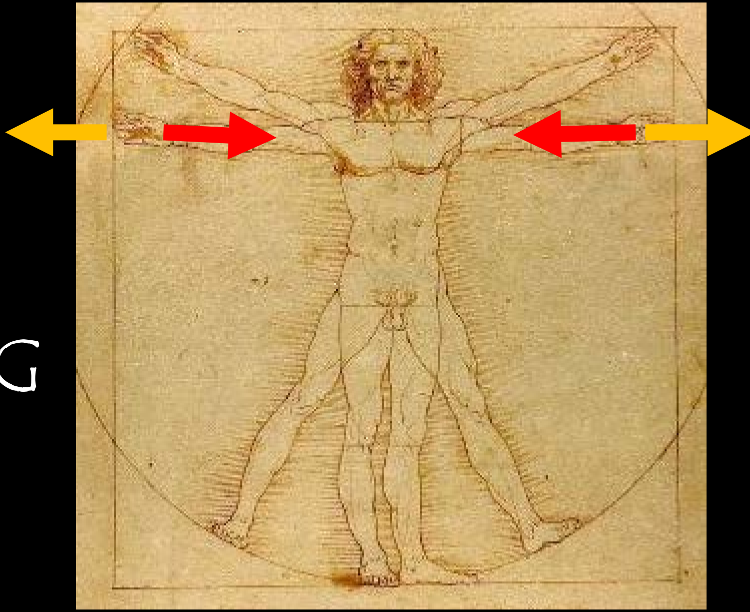
Compression
i.e.

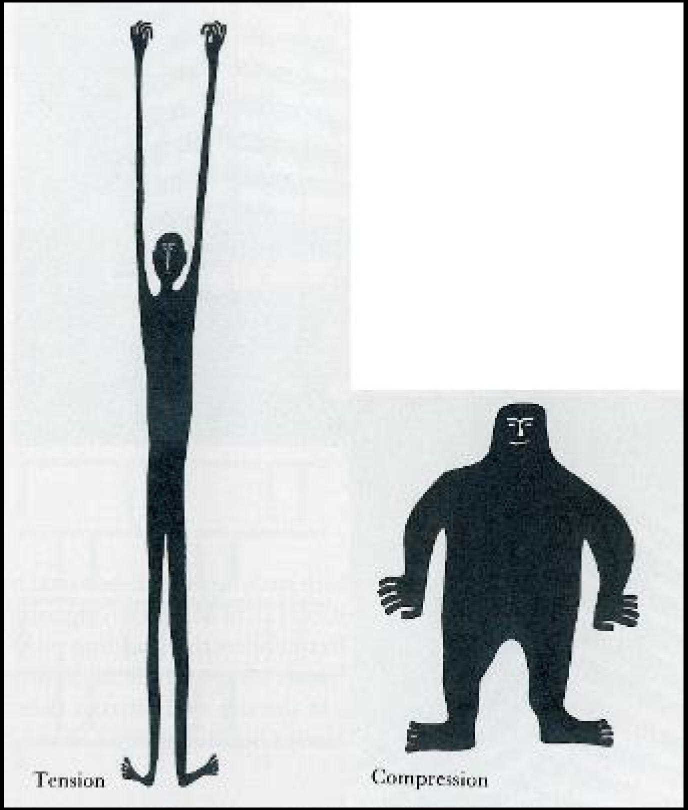
CRUSHING

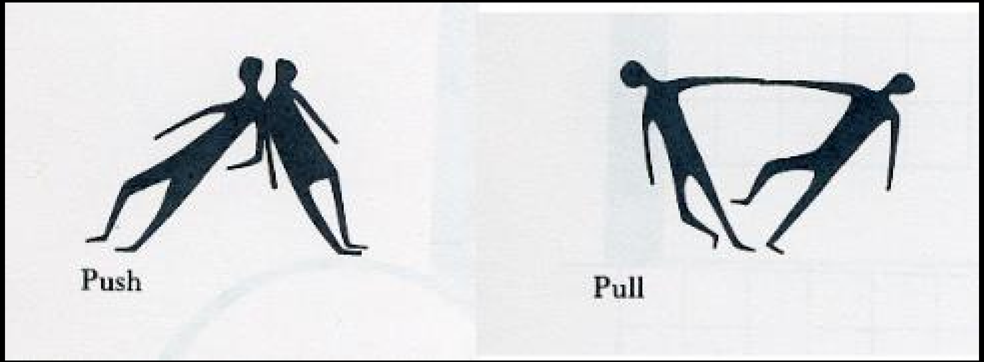


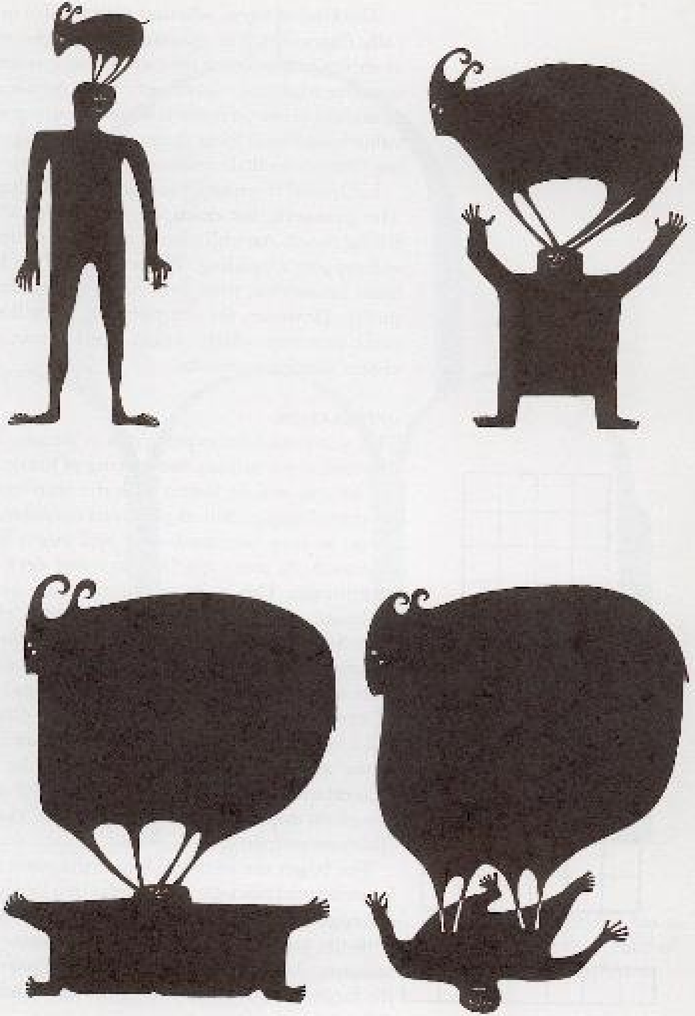
Tension
i.e.

STRETCHING



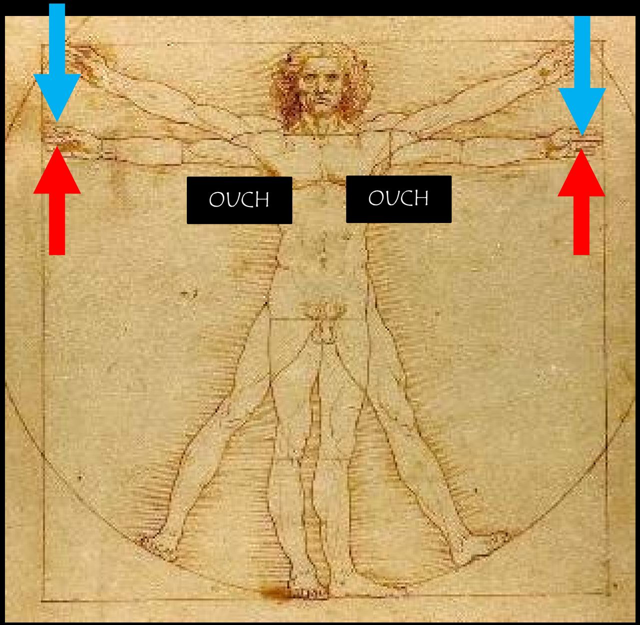

Tension
Compression

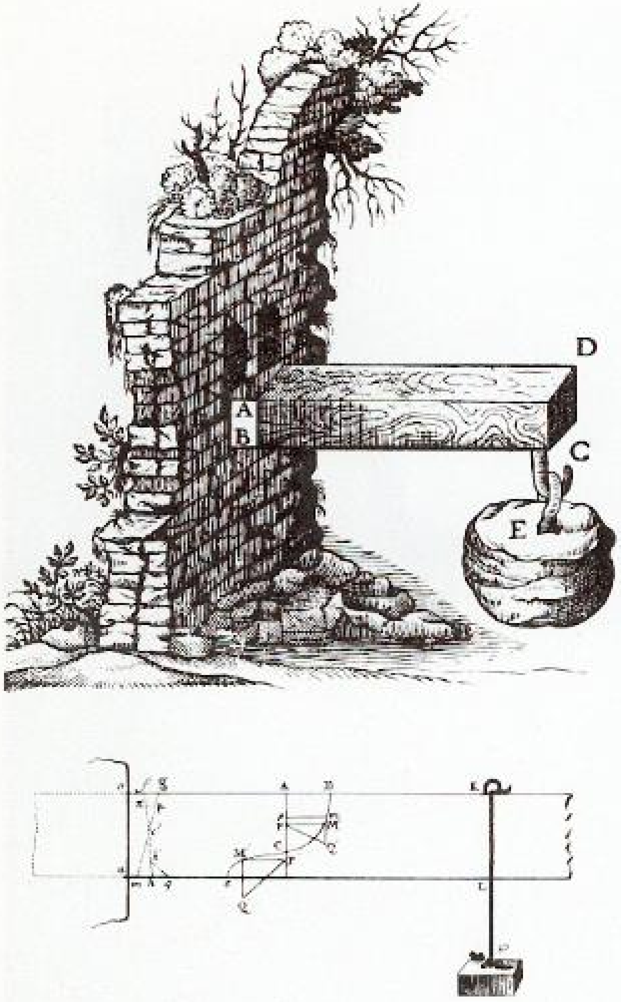

Push
Pull



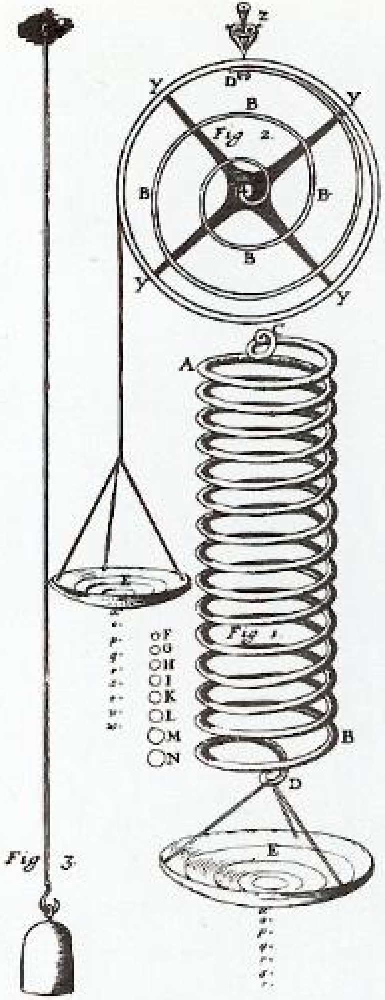
Moment / torque
i.e.

BENDING

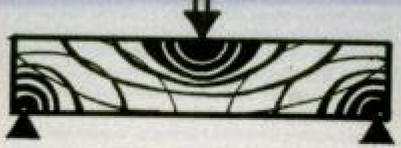




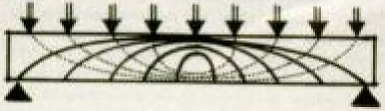
16.9 (*far left*) Studies of the behaviour of a cantilever beam by Galileo (top) and Coulomb (bottom). Galileo assumed that rotation would occur around the bottom edge at B. Coulomb more correctly assumed that the internal stresses over the depth of the cross-section would vary continuously from compression at the bottom to tension at the top, and that, in addition to these stresses acting longitudinally, there would be vertical shear stresses.



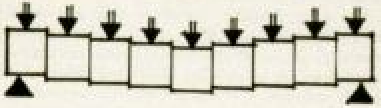
16.10 (*left*) Studies of elasticity by Hooke.



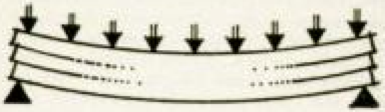
Light interference patterns showing stress in a plastic model beam under polarized light



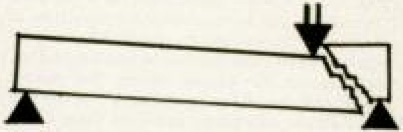
Lines of pressure and tension in a beam



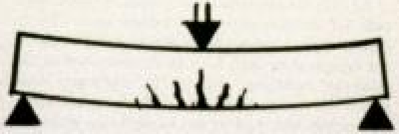
Vertical shear in a beam



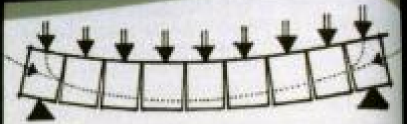
Horizontal shear in a beam



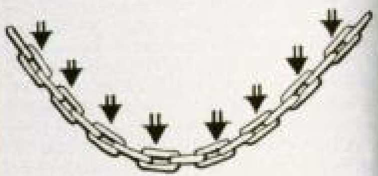
Shear failure near support



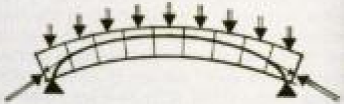
Bending failure over two supports



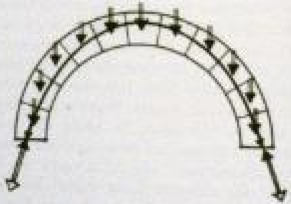
Beam bending and opening of lower surface in tension



Tensile structure alone: a chain suspended from two supports conforming to line of tension in a catenary curve



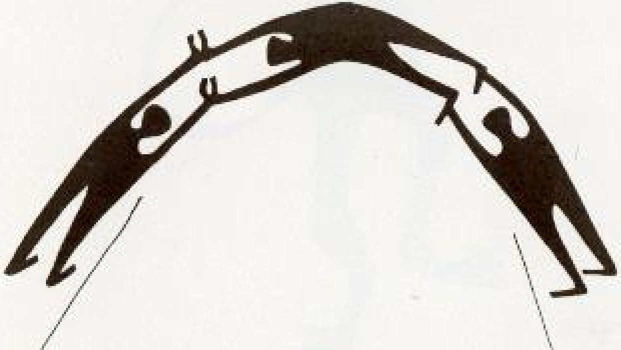
Compression structure alone: a masonry arch wedged into position along line of compression in a reversed catenary curve



In the semicircular masonry arch the line of pressure does not conform to the shape of the arch and therefore the crown tends to fall while the sides buckle out.

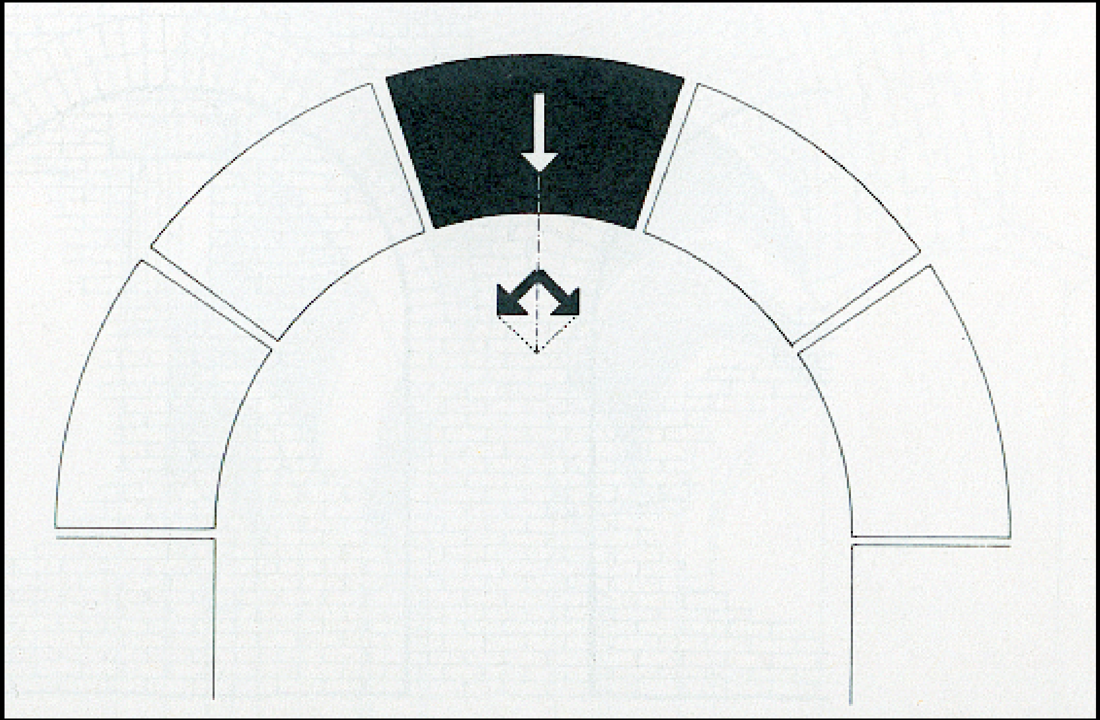
Beam

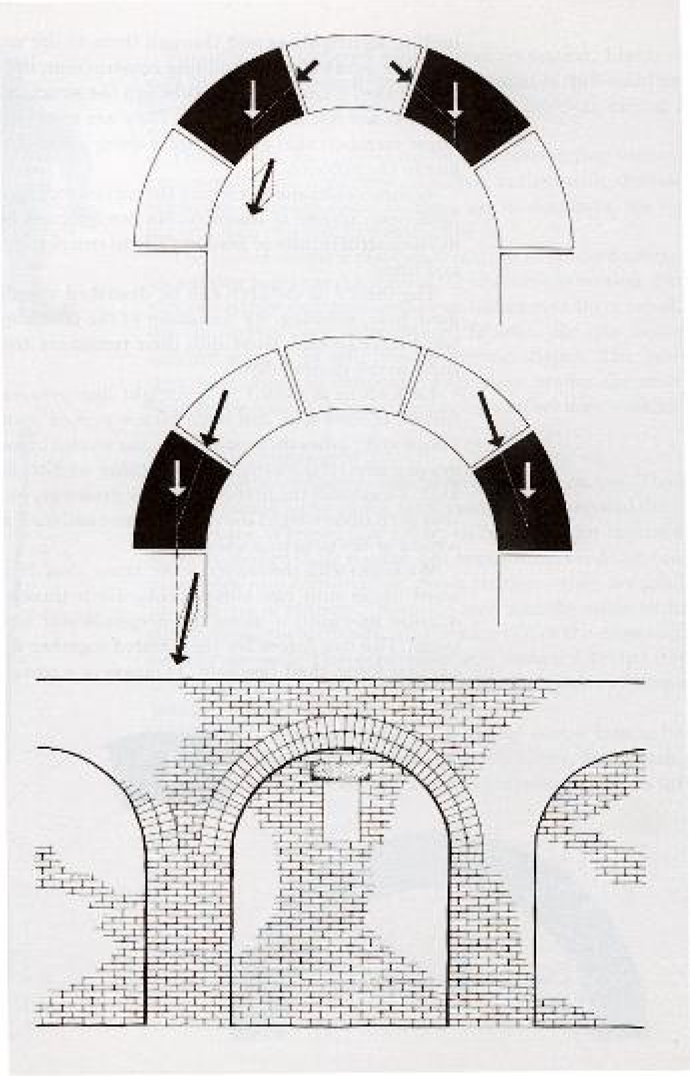
Cable



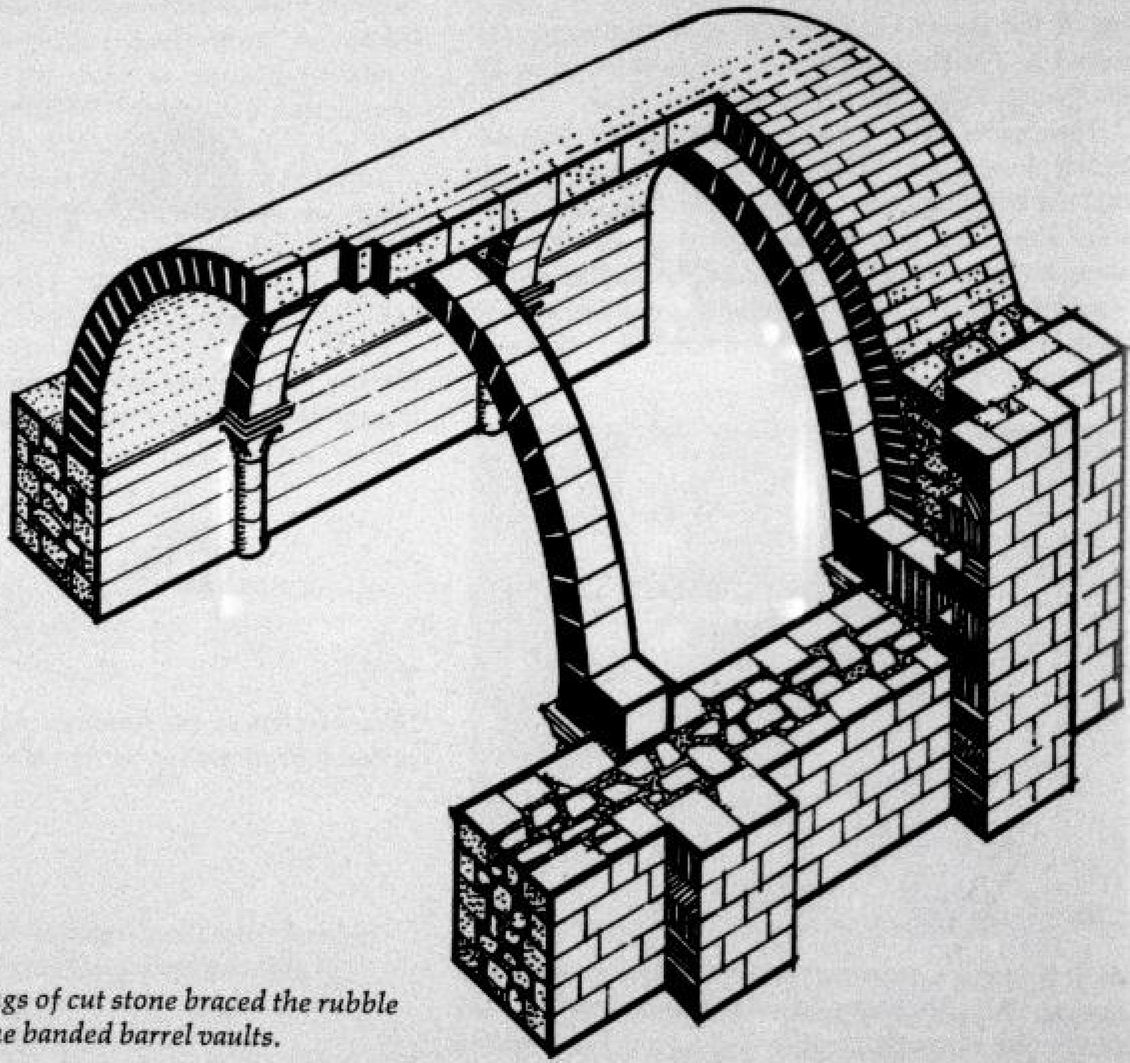
Arch

Using the Arch to span

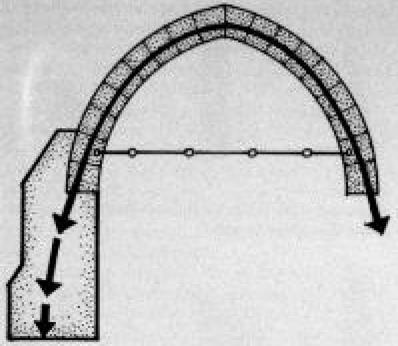




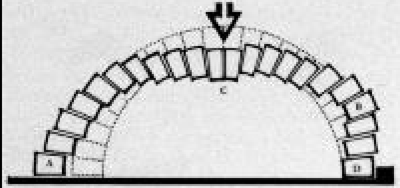
A BARREL VAULT is essentially a row of semi circular arches sitting so tightly in a row as to make a continuous, linear arched space (room)



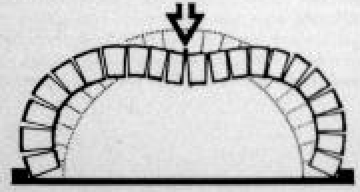
Transverse arch rings of cut stone braced the rubble shell in Romanesque banded barrel vaults.



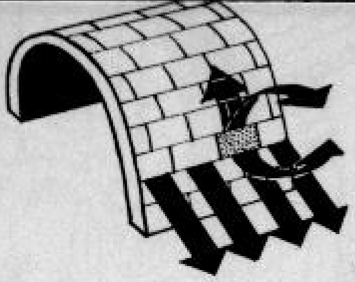
Though the pointed Gothic arch better fits the ideal line of pressure, if too acutely pointed the crown tends to rise while the sides fall inwards. (Similar to saddle failure in pointed corbel vaults)



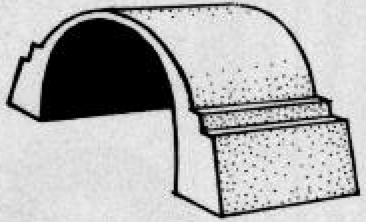
In a semicircular arch where the stones can slide the crown C will fall while the sides B are pressed out above a secure springing D or at the springing itself A.



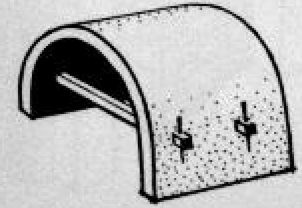
More normal is the rotational deflection of the stones during failure.



A barrel vault exerted a continuous thrust along its sides.



Usually the thrusts were dissipated in the heavy mass of the haunching and the supporting walls.

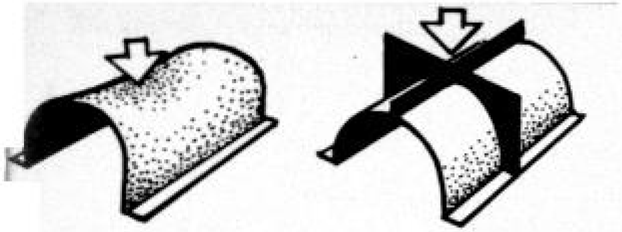


In rare instances, the masons used timber ties to restrain the thrusts of the barrel vault.

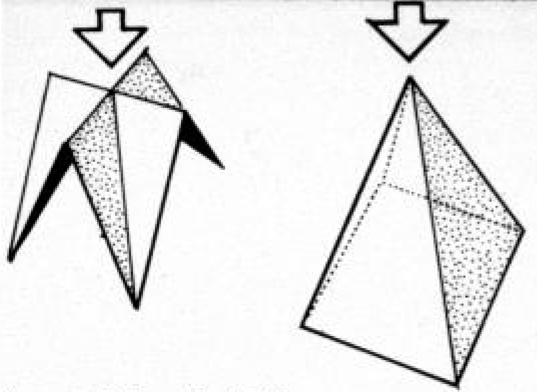
BUTTRESS

A projecting support of stone or brick against a wall

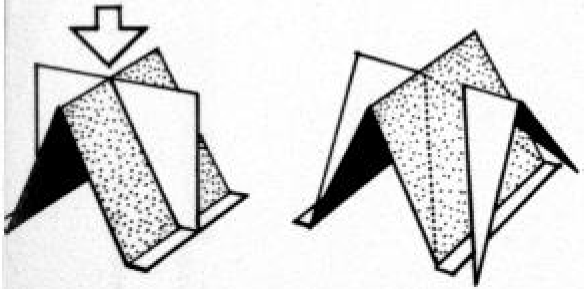
A GROIN VAULT or groined vault (also sometimes known as a double barrel vault or cross vault) is produced by the intersection at right angles of two barrel vaults.
The word "groin" refers to the edge between the intersecting vaults.
The arches may be round (Roman) or pointed (Gothic).



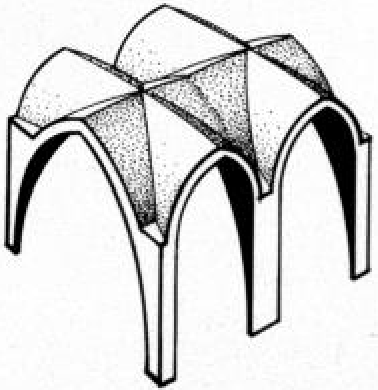
hin cylindrical barrel vaults fail when the crown alls, pushing out the sides. Thin stiffening plates an reduce this flexure.



A pyramidal roof is rigid but requires support below the sides. The cross-ridged roof can rest on four isolated supports, channeling loads down the folded groins.

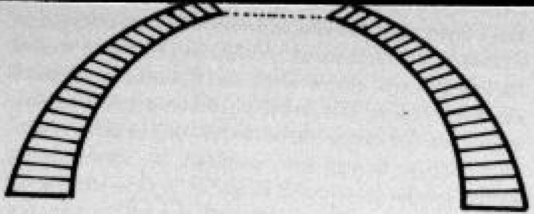


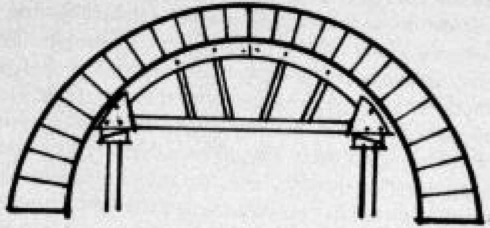
olding along the crown can replace the longitudinal tiffener. Folded ridges set transversely can brace he sides.



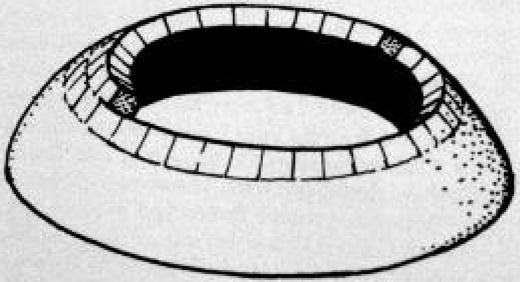
In the pointed Gothic cross vault the panels of vaulting were curved to wedge into position.

to make a DOME
you take an arch,
and rotate it 360degrees to make a circular space





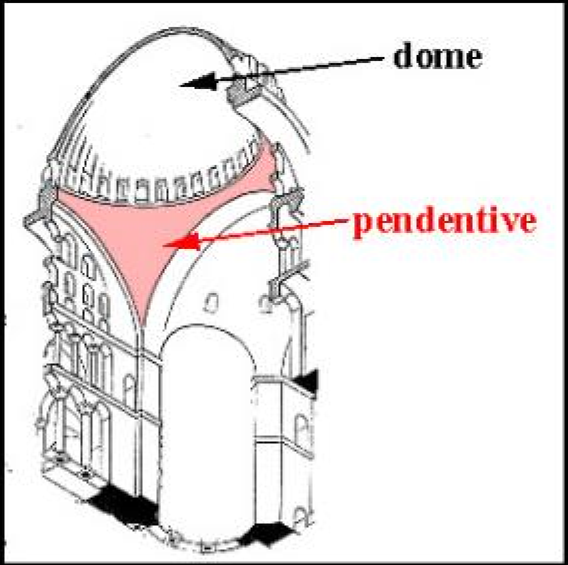
The first domes were developed from beehive corbelled domes by slightly canting the courses. Later domes with steeply pitched radiating joints required centering.

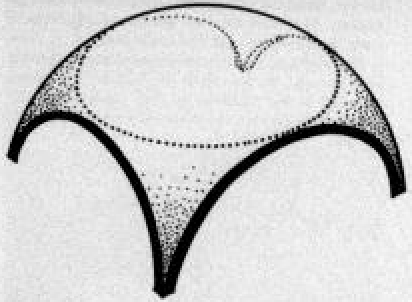


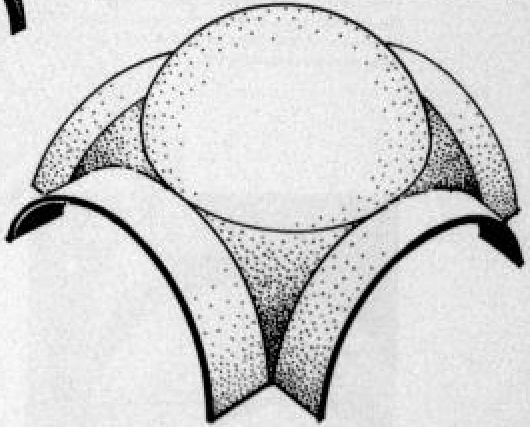
Each ring of masonry in a dome is a structurally stable compression ring.

This is what it feels like to be a dome.

a PENDENTIVE is a constructive device
permitting the placing of a
circular dome over a square room
or of an elliptical dome over a rectangular room.

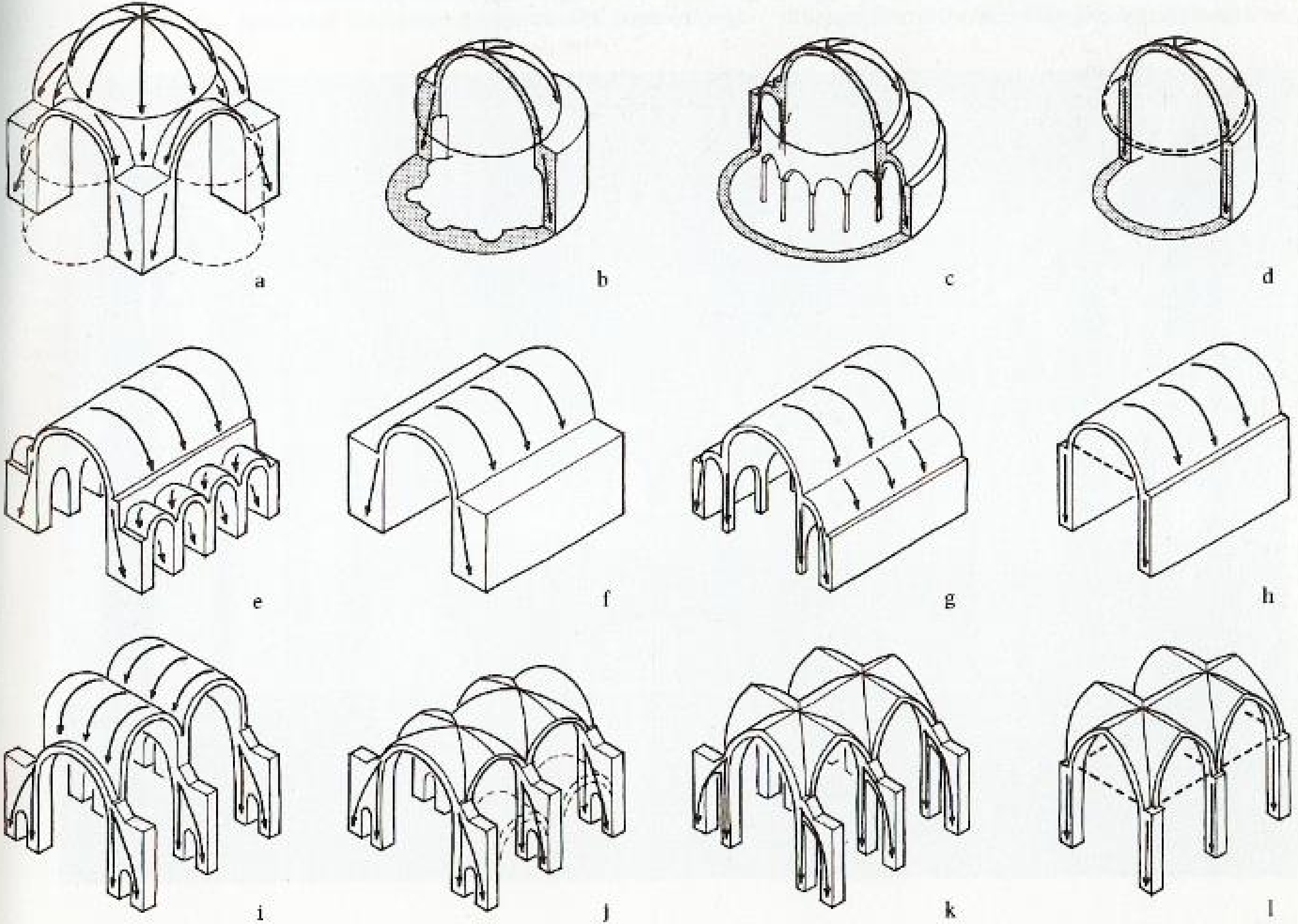






In domes on pendentives the mason could rely on the stiffness of doubly curved surfaces.

In Gothic cross vaults the folds at the groins acted as stiffening ribs bracing the entire fabric.

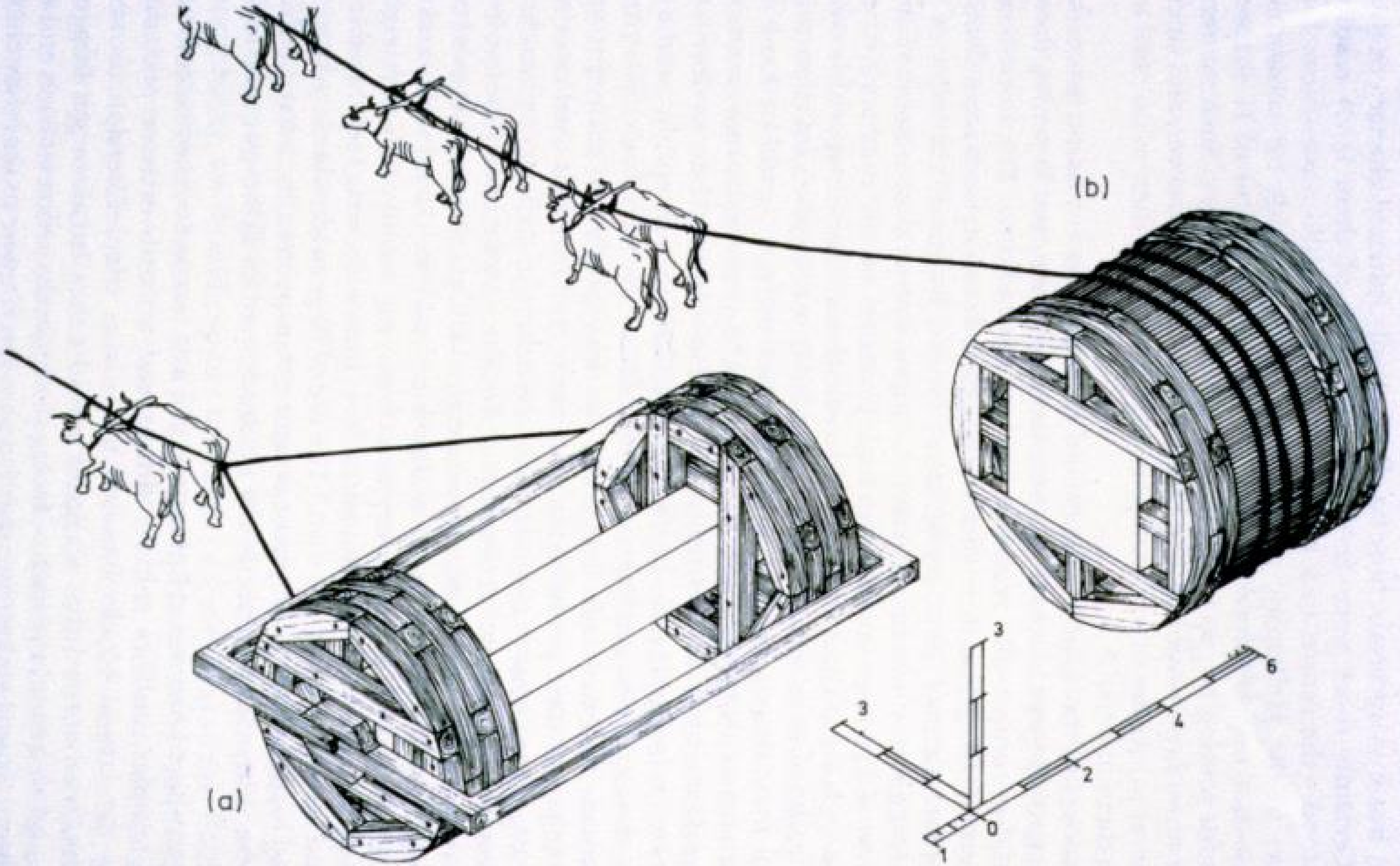

a
b
c
d
e
f
g
h
i
j
k
l

a COLUMN is a freestanding support

a PILASTER looks like a column except
that it is partially embedded in a the wall

the word 'pillar' is not really used anymore

Fig. 110. Moving a pillar



62 Colossal stone transport: isometric restoration: (a) Metagenes' method (*c.* 550 B.C.); (b) Paconius' method (first century)

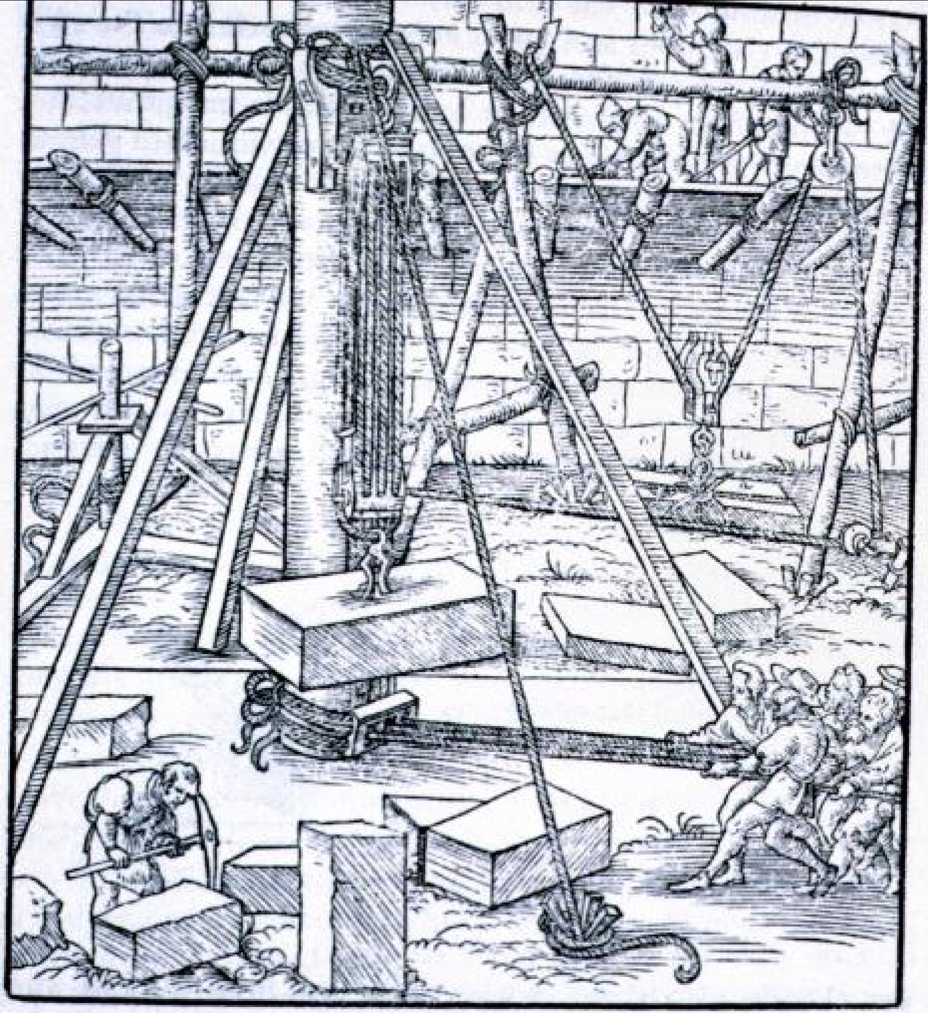
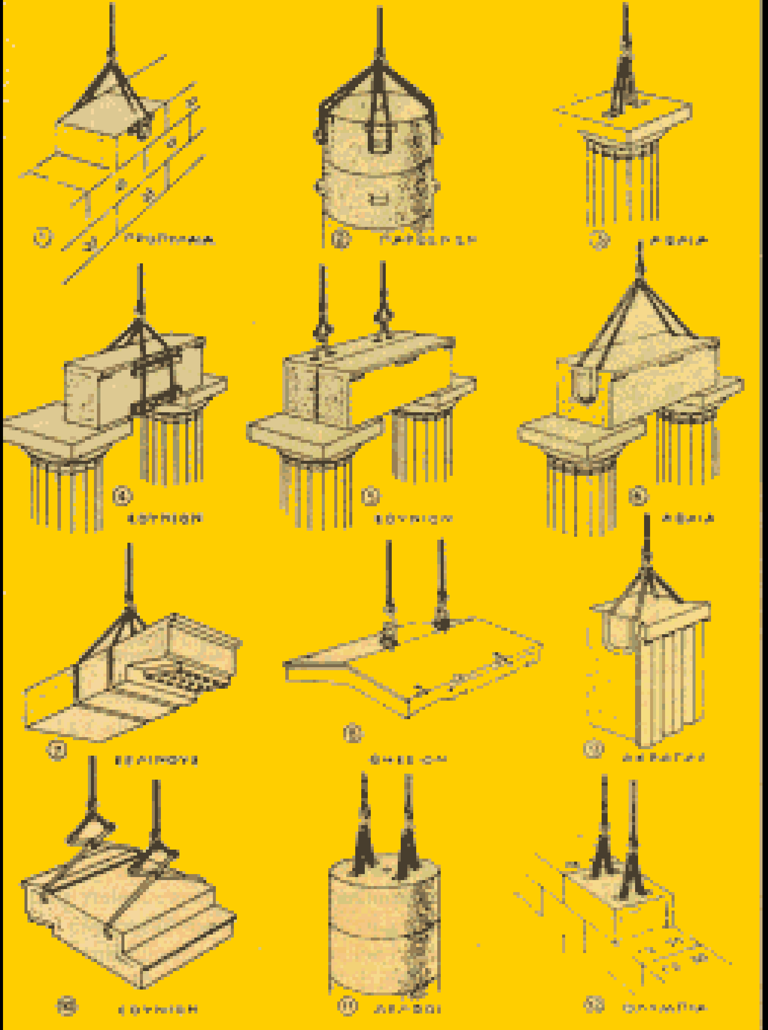


Fig. 139. Levering machinery



18

Component size and the ability to move a piece into location is a very critical aspect of understanding progress in construction through history


3L52X


PRIDE


5 Av

Aesthetics:
~ a set of principles concerned with the nature and appreciation of beauty, especially in art.
~ the branch of philosophy that deals with the principles of beauty and artistic taste.

architect engineer fabricator

I want nice connections!

Why?

Why Not?

The Vessel – New York City
Heatherwick Studios