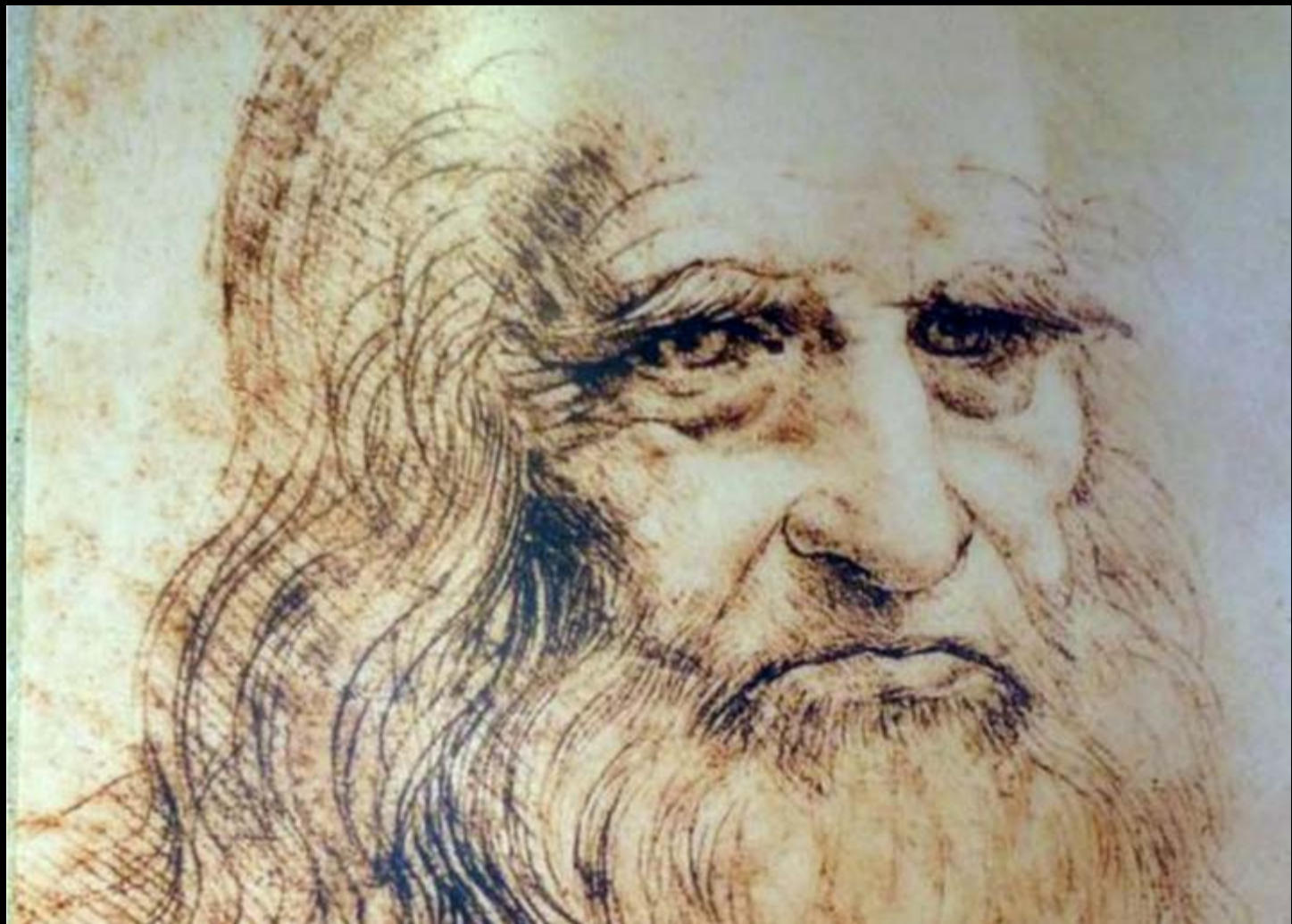


The Intrinsic Connection between
Architectural Design
and
Structural Materiality

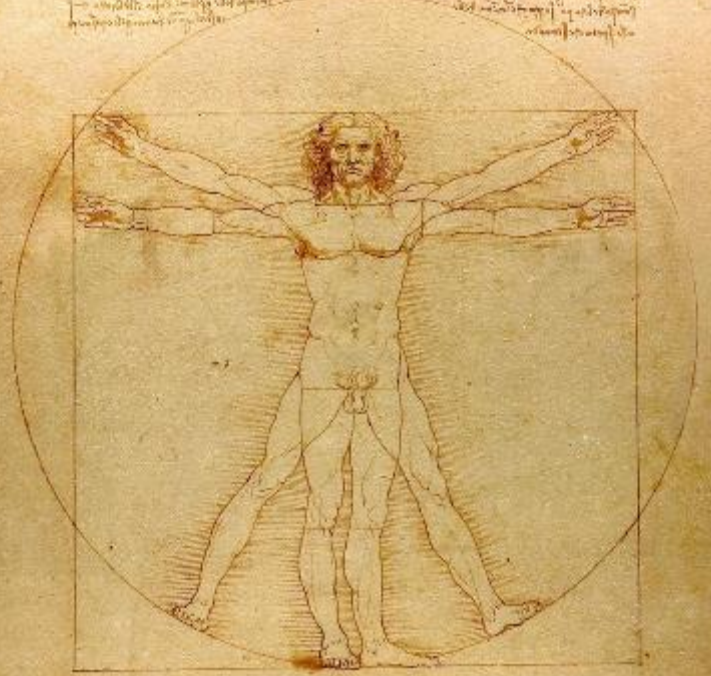
A lens for looking at...

AE 101: The History of the Built Environment

Prof. Terri Meyer Boake

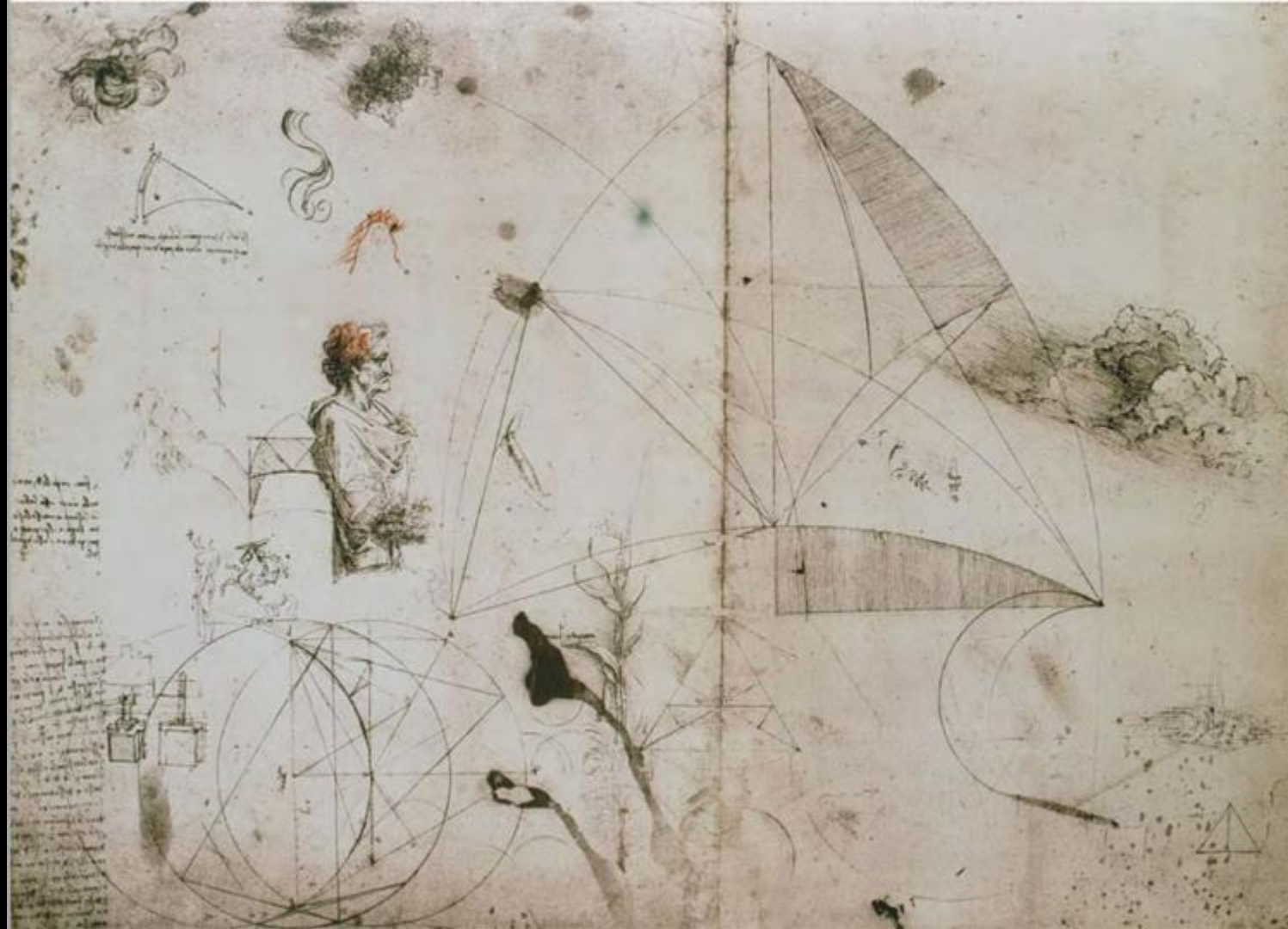


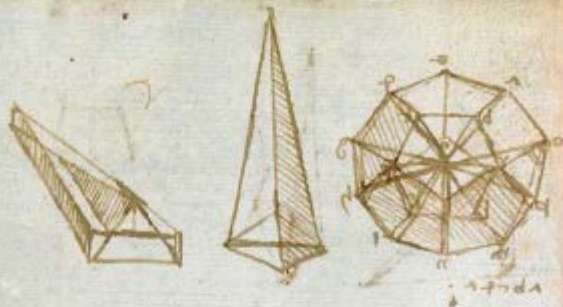
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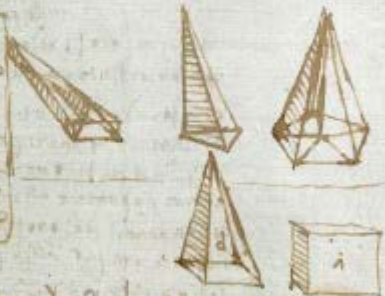
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The Sketchbook





A description of a truncated pyramid, written in a cursive script. The text is oriented vertically and appears to be a technical or descriptive note related to the diagram above.



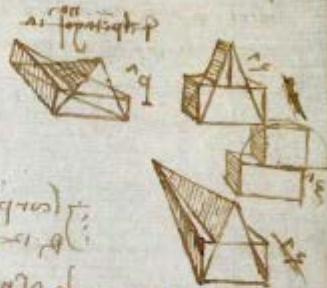
A description of a pyramid, written in a cursive script. The text is oriented vertically and appears to be a technical or descriptive note related to the diagrams above.

A description of a truncated pyramid, written in a cursive script. The text is oriented vertically and appears to be a technical or descriptive note related to the diagrams on the page.

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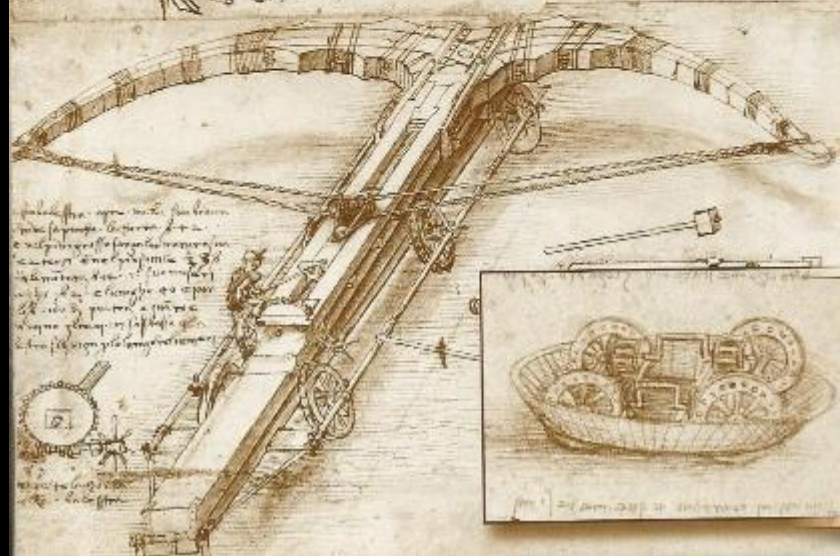


L'ingénieur militaire

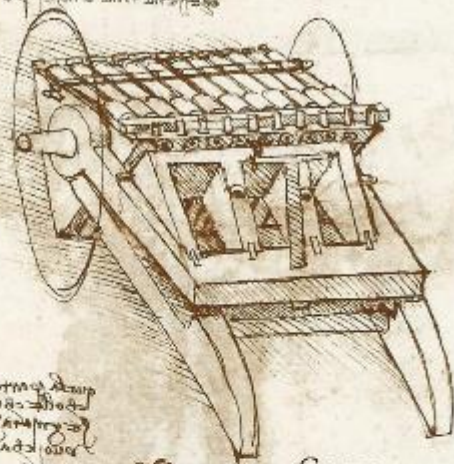


Arbalète géante

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



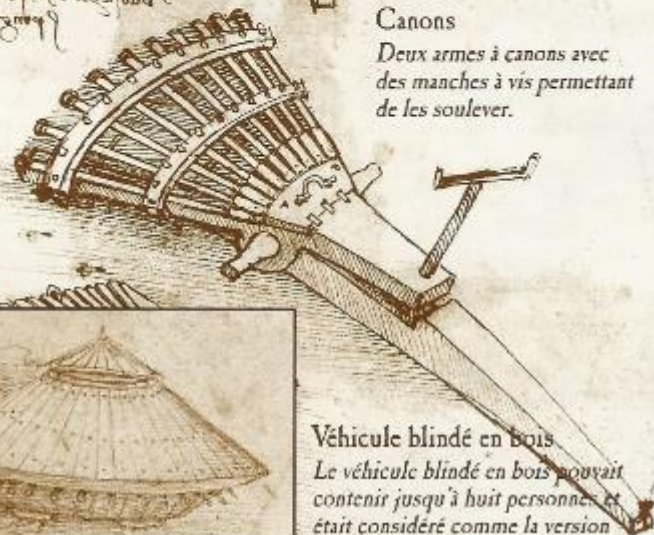
Handwritten notes in a cursive script, likely describing the mechanisms shown in the sketches.



Handwritten notes in a cursive script, likely describing the mechanisms shown in the sketches.

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.

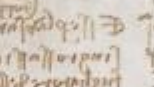


Handwritten text in a historical script, likely describing the components and operation of the mechanical device shown in the adjacent diagram.



Handwritten text on the right side of the top section, providing further details or instructions related to the device.

Handwritten text in the middle section on the left, continuing the descriptive text.



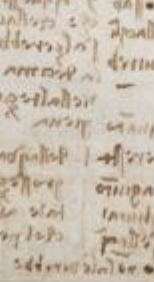
Handwritten text in the middle section on the right, providing additional information.

Handwritten text in the lower middle section on the left, detailing the assembly or use of the device.



Handwritten text in the lower middle section on the right, providing further technical details.

Handwritten text in the bottom section on the left, concluding the description or providing final notes.



Handwritten text in the bottom section on the right, providing final remarks or a signature.

Handwritten text at the top of the right page, describing the device or its parts.



Handwritten text on the right side of the top section, providing details.

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Handwritten text in the middle section on the right of the right page.

Handwritten text in the lower middle section on the left of the right page.

Handwritten text in the lower middle section on the right of the right page.



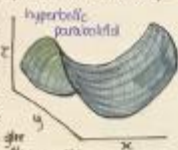
Handwritten text in the bottom section on the left of the right page.



- a hyperbolic paraboloid is a doubly ruled surface shaped like a saddle

- Some forms an aesthetically satisfying shape has been sought primarily through study 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 surroundings.

- This terminal at Kennedy Airport & Urban's Skyway Opera House have a hyperbolic paraboloid shape. The wind-blown walls had to be considered not as smooth continuous thin shells but as sets of ribs, paved side by side to give



a deeply corrugated post-tensioned concrete slab, by introducing the actions inevitably brought into play by the desired sharply pointed eaves.

- multi-story buildings over long spans of plan and general height than long arches - the need to accommodate the varied demands of oblique & unpredictable future demands have become a major constraint on the choice of structure.

- Sometimes 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 as local resources, fluctuations in prosperity & the objectives and the priorities of those in control.

Chapter 4: 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 posed on the structure as a whole to the foundations are statically 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 external loads that 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 & related 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 & may differ significantly from one another in their effect on the form & material of the structure, and the characteristics determined by the nature of its construction. i.e. loads imposed by functions 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 & subsiding of ground when the expansions & contractions to which these loads are given are restrained. - Estimating the net effects of most of these active loads at the point where the structure is supported are the normal practice, they are also dependent on the precise manner of construction. - Examples of weather loads include internal air pressure.

Associated Movements & Deformations

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

Dynamic & Static Loads

- static loads change slowly enough to allow the resistances and are classified by deformation to keep pace with them. - rapid changes of loads involve different acceleration which cause inertial resistance to be more being introduced, sometimes balance is required.

- the amount of force a dynamic load takes to reach its peak is proportional to less than the natural period.

- Irregularly applied loads have the effect of a load of the same magnitude applied slowly - irregularly repeated or periodic loads need damping effects if their position relative to the load varies the effect of the previous application. - static loads are the most important ones for most buildings.

- Dynamic & periodic loads of irregular occurrence magnitudes are usually specified in frequent occurrence. - The commonest dynamic load is wind. The external form & configuration of the structure should optimize the form & configuration of the structure to minimize the pressure on different parts.

- reflective dynamic effects are usually confined to structures with long natural periods of vibration. (Tall slender buildings, chimney stacks, ...). The effect can be greatly minimized by dampening if the cross-section is one that leads to a resonance of the cross-section & structure. Damping in deep foundations & structures of members coupling in deep foundations & structures of members coupling in deep foundations.

- dynamic loads due to earthquakes are less common. - they are inertial loads acting on all parts of a structure above the ground as a result of any slight displacements of its foundations. They depend on the mass of the structure & direction of the active structure & its elements, on whether they respond by bending, sliding, and with it dissipate energy.

Internal Actions

Force, Tension, Compression, Bending, Torsion, & Shear

- A single force is represented by a straight arrow and a pair of equal & opposite parallel lines, not used to show direction, by a curved arrow.

1. Tension - pulling apart. The force is represented by a straight arrow pointing away from the center of the element.

2. Compression - pushing together. The force is represented by a straight arrow pointing towards the center of the element.

3. Bending - the action of a force applied to one end of a member, causing it to curve. The force is represented by a curved arrow.

4. Torsion - twisting. The force is represented by a curved arrow around the axis of the member.

5. Shear - the action of a force applied to one end of a member, causing it to slide. The force is represented by a straight arrow pointing parallel to the surface of the member.

6. A force applied to one end of a member, causing it to rotate. The force is represented by a curved arrow around the axis of the member.

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Structural Requirements

4.1. The Basic Structural Requirement

- In order to have all these systems & not lose a large percentage, the structure must be designed to fit the space provided by the structure for the use of all daily life.

4.2. The Requirements that the Structure Must Satisfy

- If the structural requirements are satisfied, the structural elements of a building should have the maximum strength & stiffness.

- In complex structures the nature of the elements is determined by the nature of the form & work - static equilibrium.

4.3. Static Equilibrium

- For a system to be in static equilibrium, it must have a zero linear momentum in any direction, it must have a zero angular momentum in any direction.

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

4.4. The Nature of the Load

- Both are considered elements. The loads should fall in the plane of the structure & the structure should resist them. The nature of the load determines the nature of the structure & the nature of the structure determines the nature of the load.

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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:

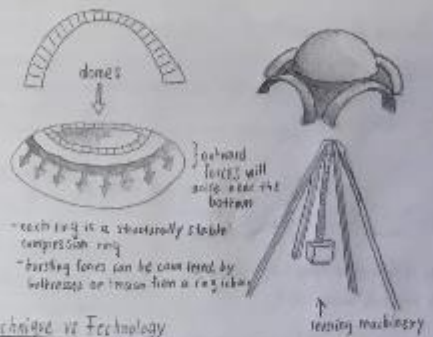
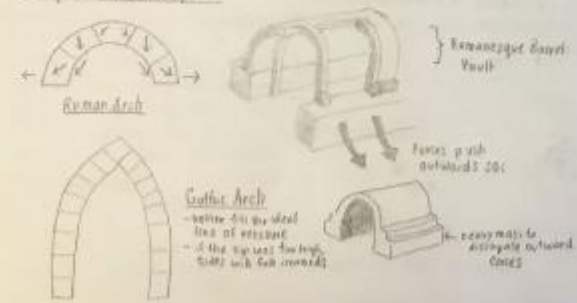
- natural material
- great for compression
- some stones are better for construction - eg sandstone is very brittle/cracks easily
- stone gets destroyed by pigments
- water imparts materials, moss and lichens can also deteriorate

Forces

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



Using the ARCH to Span

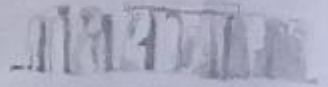


Technique vs Technology

'trial and error' vs. mathematics and physics

Stonehenge

3000 BCE, Wiltshire, England
 - historians not sure how it was built
 - sundials, clocks, advanced stone placement



Law of Hammurabi

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: wind ramps to move heavy objects (stones)



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

- surrounding currently in bad repair
- rough stone to restore because sandstone is eroding

MIT Chapel

Cambridge, Massachusetts (1956)
Eero Saarinen

- cylinder
- modern version of, very simple
- little arches along bottom
- most along bottom that reflects light into the chapel
- tall narrow walls
- skylight over central pedestal "pavilion" tower
- interior brick design - pattern is different from exterior

MIT Chapel



Rothko Chapel

Houston, Texas (1960)
Philip Johnson

- extremely simple and reflects of modern movement
- drawing issues / not roof made slanted

Philips Exeter Academy Library

Exeter, New Hampshire (1932)
Louis I. Kahn

- modern, regular plan, "formally" symmetrical
- form is the design
- exterior is brick, interior finished concrete
- large open space + galleries



Philips Exeter Library

Rahn Museum of Art

Penn State University, State College, Pennsylvania (1960)
Charles W. Moore

- "post modern"
- revival of classical architecture through art
- arches - columns, columns (columns on balconies and roof)
- by masonry and important
- worked with the masonry (small bricks with very adaptable in different shapes in structure)

Brown College

Rice University, Houston, Texas (2002)
Michael Graves

- masonry, large openings
- decorative brick laying
- flat roofline, not very heavy, less visual participation
- wooden arches in support ceiling

- Recalling building tradition? same style with brick



Herring Hall

Rice University, Houston, Texas (1934)
Cecil Balch, Richard

- "flat modern"
- concrete made of stone + concrete (specialty manufactured)
- column - almost brick pattern
- very quiet
- square panels + the window grids
- flat green square details

Herring Hall, Rice University



Burns and Charles Deering Hall

Rice University, Houston, Texas (1934)
John Talbot Associates

- arches, capitals
- concrete brick allowing, some are glazed
- classical column (flat, square, classical column)
- decorative masonry ceiling

From a stylistic perspective, it has inspired an eclectic attitude towards styles and materials

Brick can be made at large percent quality and long from the building to make a form concentrating time saving at height in various materials

Museum of Modern Art

San Francisco, California (1965)
Mark Taper

- substantial, square modern, simplified
- strong
- fairly symmetrical
- has a front (front of facade, front panels)
- all brick construction done in brick zones



Museum of Modern Art, San Francisco

Milken Science Complex

Penn State University, State College, Pennsylvania (2011)
Richard Tishley Architects

- massive light tower
- brick panels that were prefabricated; construction goes eastern
- special panel in the window-de

Dr. Chau Chak Wing Building

Sydney, Australia (2015)
Frank Gehry

- red bricks, but corners in copper/red
- custom prefabricated brick panels



Milken Science Complex

AREA LAYOUT AND THE AREA ABOVE
 THE PART OF THE BUILDING WHICH IS
 TO BE USED AS A THEATRE SEATING



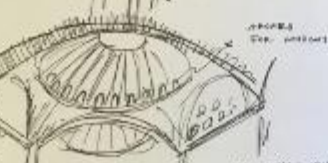
SUBSTANTIAL PROVISION
 TO BE MADE FOR THE
 SEATING OF THE THEATRE



STAIRS FOR THE GROUND FLOOR SEATING
 TO BE PROVIDED UNDER THE THEATRE



MAJOR SURVEY
 IDENTIFICATION
 TO BE MADE WITH THE VIEWING



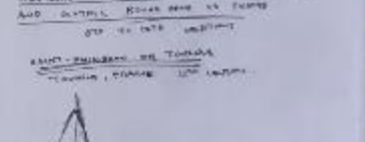
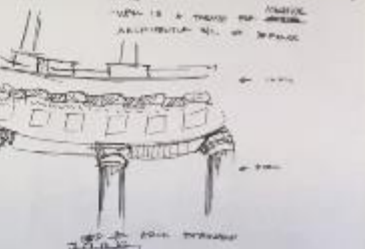
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CATHEDRAL - GOTHIC - FRANCE - 14th C.

ARCH 1

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CATHEDRAL - GOTHIC - FRANCE - 14th C.

ROUNDED ARCH

ROMANESQUE - FRANCE - 11th C.



ROUNDED ARCH

11th - 12th C.



ROUNDED ARCH

11th - 12th C.



ST. BENOIT'S CATHEDRAL - LUXEMBOURG - 13th C.



[THE RENAISSANCE]

16th - 17th C.

IN INTERIOR OF CHURCHES

THE LATER RENAISSANCE



THE RENAISSANCE

16th - 17th C.

THE RENAISSANCE

16th - 17th C.

THE RENAISSANCE

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THE RENAISSANCE



CLASSICAL BUILDING

16th - 17th C.

CLASSICAL BUILDING

16th - 17th C.

CLASSICAL BUILDING

16th - 17th C.

CLASSICAL BUILDING

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CLASSICAL BUILDING

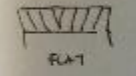
ARCHES



SEMICIRCULAR



SEGMENTAL



FLAT



POINTED OR GOTHIC

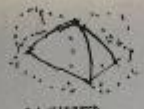


FLAT-TOPPED OR TUDOR

VAULTS



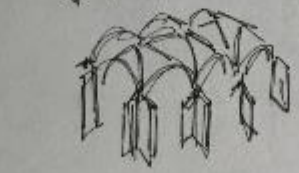
BARREL VAULT



CLOISTER VAULT



GROIN VAULT



DOMES



DOVE



PENDENTIVE DOME



PENDENTIVE DOME W/ HALF DOMES



PENDENTIVE DOME W/ BARREL VAULTS



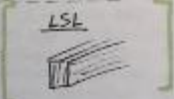
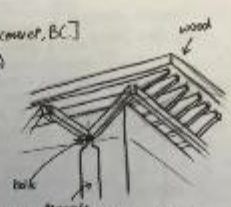
DOVE AND PENDENTIVES

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 panels 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 enables 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 dimensions. (strands usually 3mm thick & 2.1mm 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)

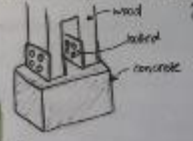
Storey Park (Hastings Visitor Center) - [Nanaimo, BC]
 → government buildings MUST use wood (law)
 → beams are spanning at 90° angles
 → use bolts in heavy member
 → steel hidden inside



Hull Center for the Performing Arts [Ongon, USA] - Hardy Holzman Pfeiffer Associates
 → can see cracks on wood
 → architect wanted to look like a book
 → wants to conceal that steel that is holding everything together



Gene H. Krayer Pavilion (Lund University) [Göteborg, Sweden] - Paul Gundersen / Fulltime Holten Architects
 → how to connect wood to foundation



△ How do you curve glulam?
 if it's heavy enough, it does not by itself

Jackson-Triggs Niagara Falls Dining [Niagara-on-the-Lake, Ontario] - KPMB Architect 2001
 → steel & timber
 → steel joints: corrugated decking, steel plates in wooden beam
 → windows not at eye level

Scarborough Arts Center Library [Scarborough, ON] - USA Architectural Partners & Phillip H. Carter Architects
 → wood runs through glass
 → exposed bolts

Richmond City Hall [Richmond, BC] - KPMB Architect with Holten Eakler 2000
 → cross-laminated pattern

Wares Terminal [Muroran, Japan]
 → curved wood

BC → trees often in the rain but it's not getting rain through because of glue warning.



- CHINA - GREECE

- **Temples in China**
 - o wooden pillars, all freestanding
 - o multiple columns & designs
 - o inspired by vegetation
 - o axes limited by ability of material to span
 - o All temples had a different sense of individuality!
- **Temples in Greece** at 600s, 500s BC
 - o formalised open space
 - o surrounded by colonnade (peristyle)
 - o symmetry of space
 - o allows light to enter
 - o respect is given to columns
- **Order of columns** → Doric order
 - o 4th century BC
 - o Doric temple
 - o together lines
 - o participation (Greek)
 - o boy holding Egyptian → stylised like ph. and/or basins
- **Order of columns** → Ionic order
 - o 5th century BC
 - o steps & stairs

- **Order of columns** → Doric order
 - o columns → all different widths in height
 - o similar inside temple
 - o respecting all human body
- **Composite order**
 - o columns carved in one piece
 - o heads → add maximum into their art

- **Composite order**
 - o Doric + Ionic
 - o Doric capital
 - o decorative around perimeter
- **Composite order**
 - o columns carved as blocks to hold up porch
 - o **Composite order** (Ionic)
 - o Ionic columns, mainly
 - o **Composite order** (Doric)
 - o Egyptian temple architecture
 - o **Composite order** 4th BC
 - o style of architecture more refined

- **The classical style** → used stone blocks
- **Order of columns**
 - o propped up
 - o stone arches
 - o **Composite Italy**
 - o walls plastered over
 - o brightly coloured



NEW BUILDING WORK

THE OUTDOOR ENVIRONMENT

- **The Earth and the Sun**
 - o Sun is an important factor in the lives of people and buildings
 - o Warmth & buildings by direct radiation
 - o at warming the surrounding
 - o illuminates outdoor climate, surfaces, produces vitamin D
 - o Sun is both a giver of life & destroyer
 - o All important materials burn, promote skin cancer
 - o particles include electromagnetic radiation
 - o Earth is closest to the Sun in winter, at the orbital eccentricity point to slightly increase seasons
 - o seasons created by tilt between axis of earth's rotation & a perpendicular to the plane of its orbit

The Summer Solstice

- occurs when the Sun rays are at their longest at an orbital position (maximum around June 21)
- The Sun is seen for a longer period of time on this day than other days
- without season, occurs later since land & water with considerable thermal capacity warmer days
- later, partly due to the stored energy in earlier air (considering the effect)
- winter solstice - opposite (Dec 21)
- Polar holes at daylight



The Equinoxes

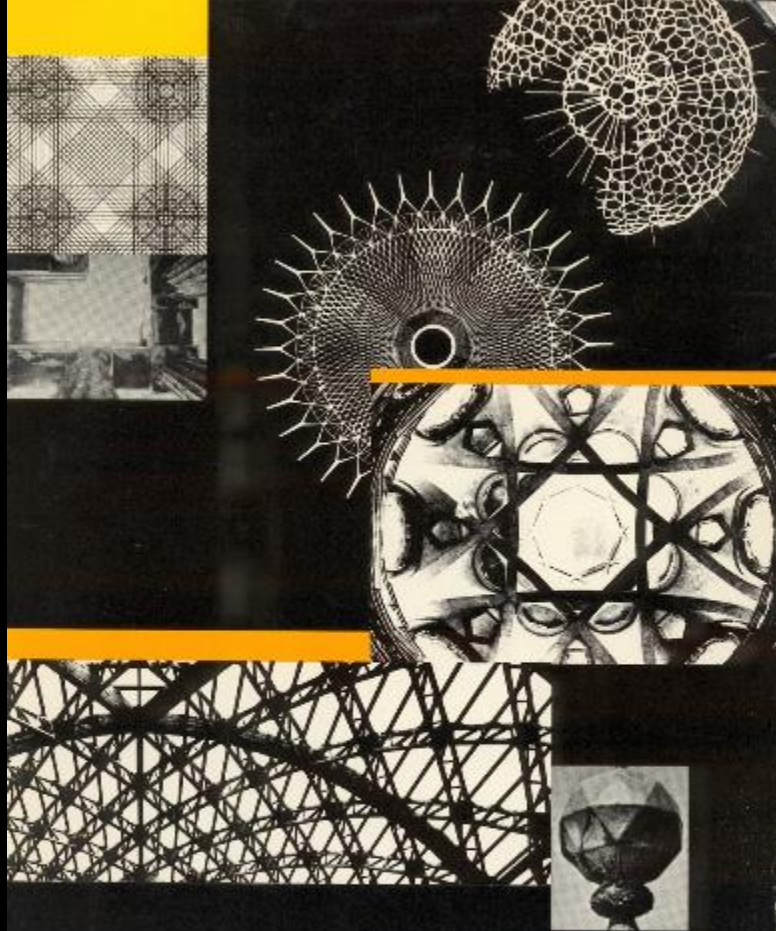
- March and September at equinox
- 12 hours of daylight
- North and South Pole are equidistant from the Sun
- Sun rises and sets exactly the same length of time
- Sun travels along horizon for 24 hrs

The Annual Cycle

- See two parts of a year being spent on the planet is expected to direct sunlight equally with the time
- at the poles, with portion of sunlight comes in one direction for each period
- the greater, with day of the year is evenly divided between daylight and darkness
- at intermediate latitudes, longer summer days compensate for shorter days in winter

Effect of Solar Radiation on Earth

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

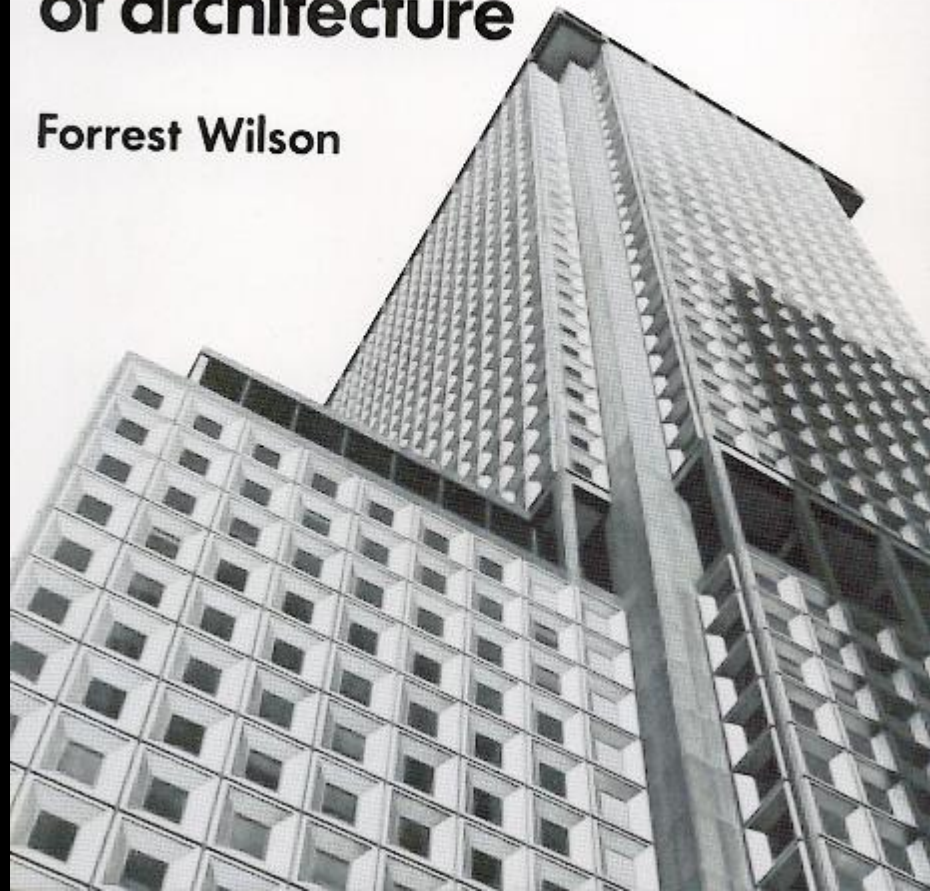


**Developments in
Structural Form**

Rowland J. Mainstone

STRUCTURE: the essence of architecture

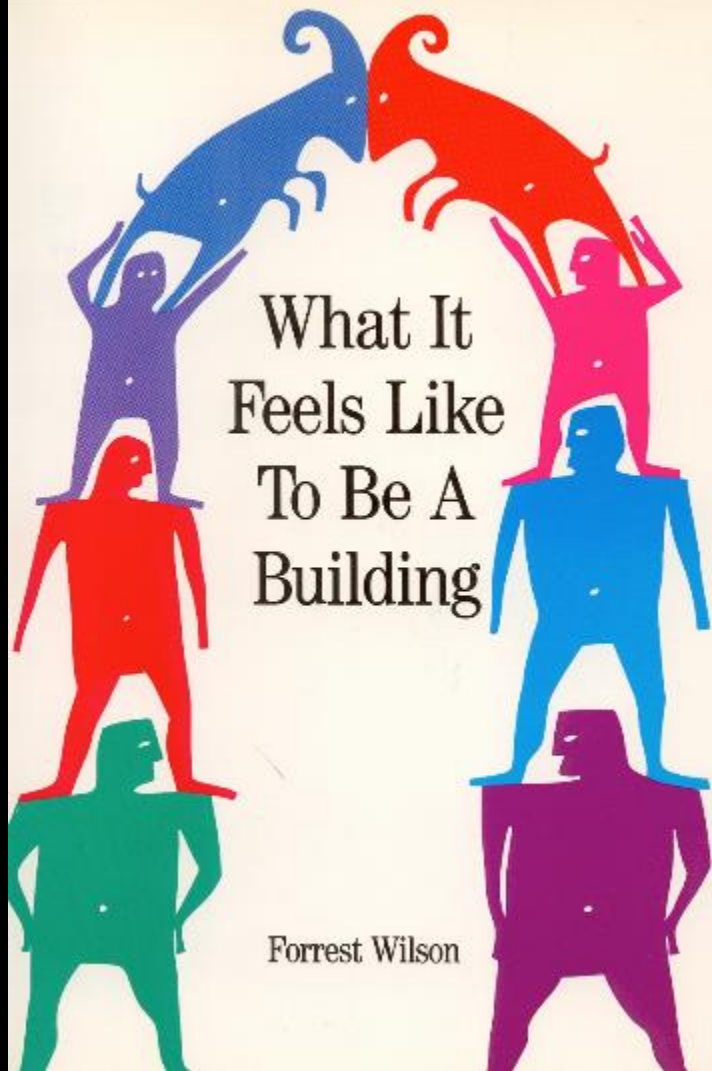
Forrest Wilson



forces

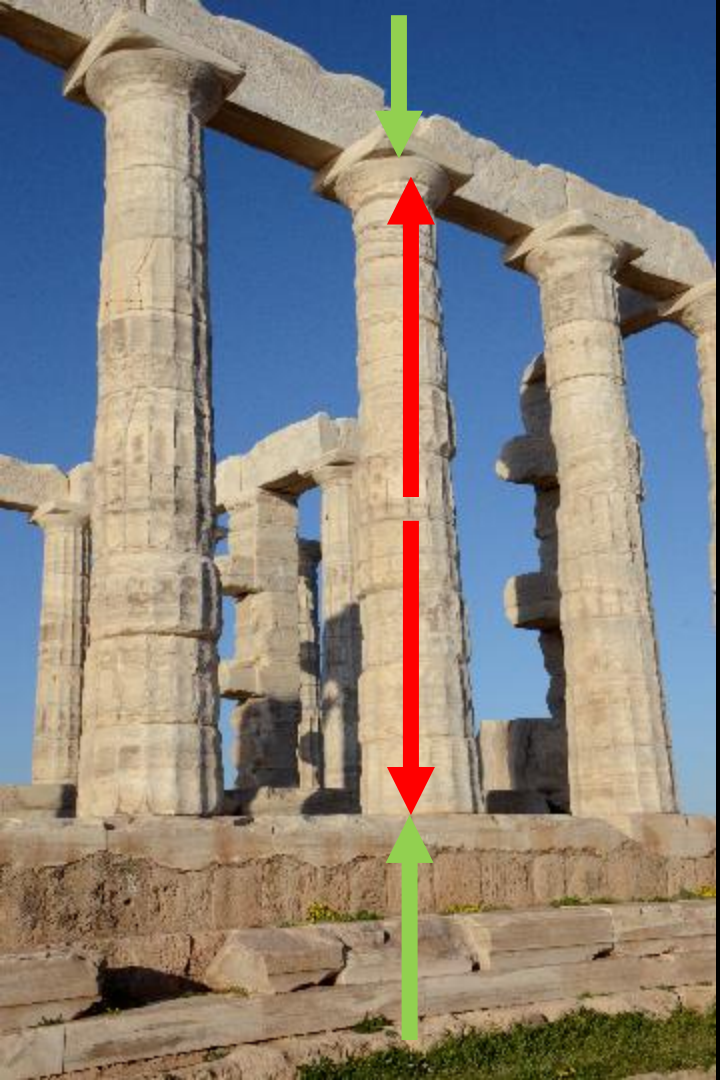
Some materials are better than others
at resisting forces

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



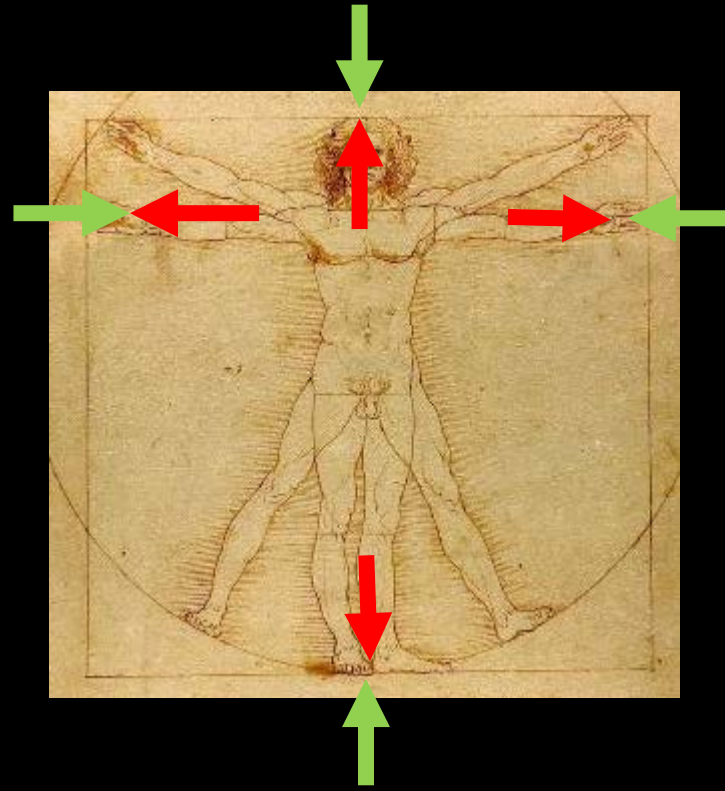
What It
Feels Like
To Be A
Building

Forrest Wilson



Compression
i.e.

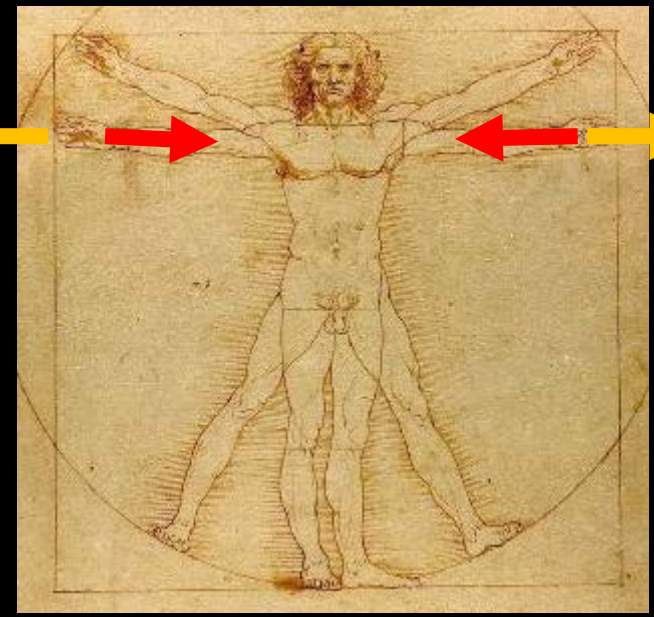
CRUSHING

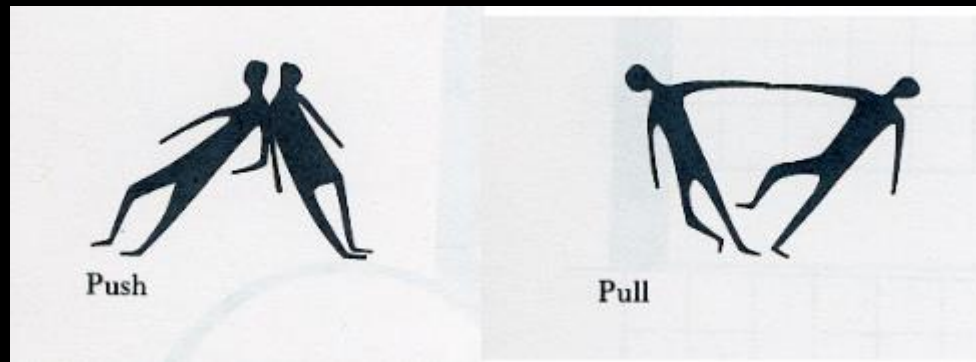
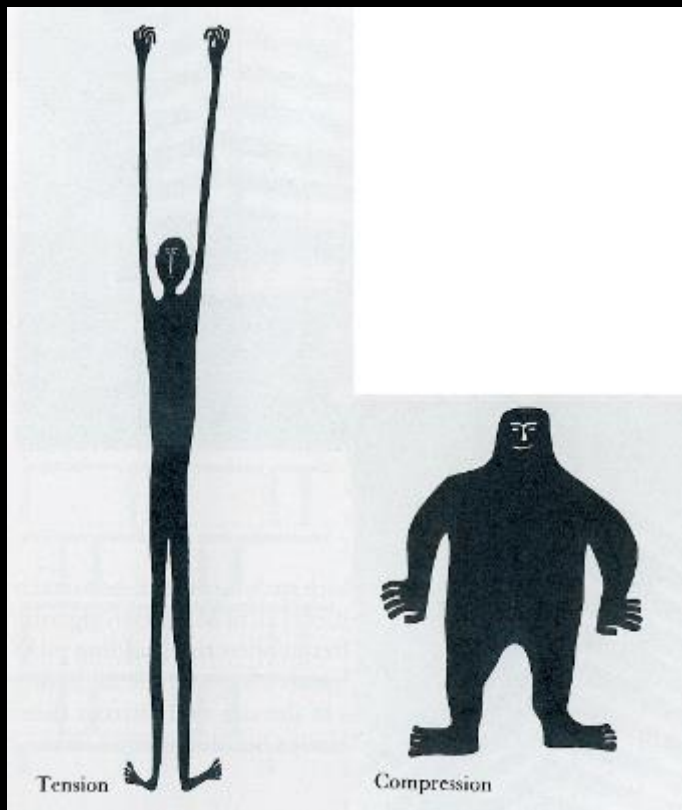


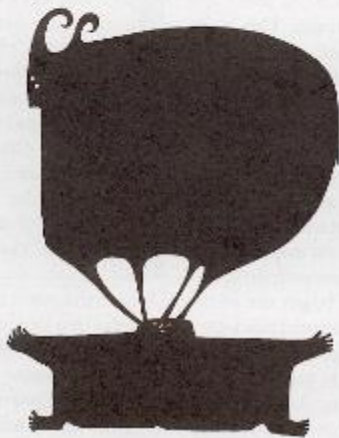


Tension
i.e.

STRETCHING



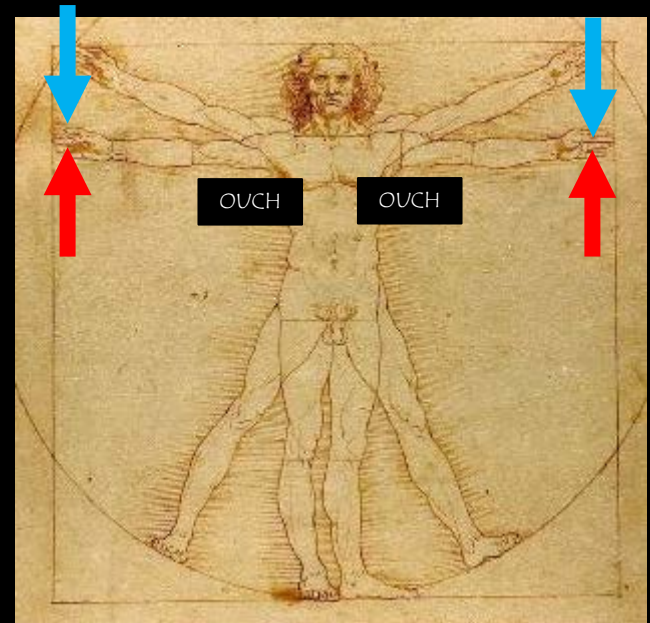


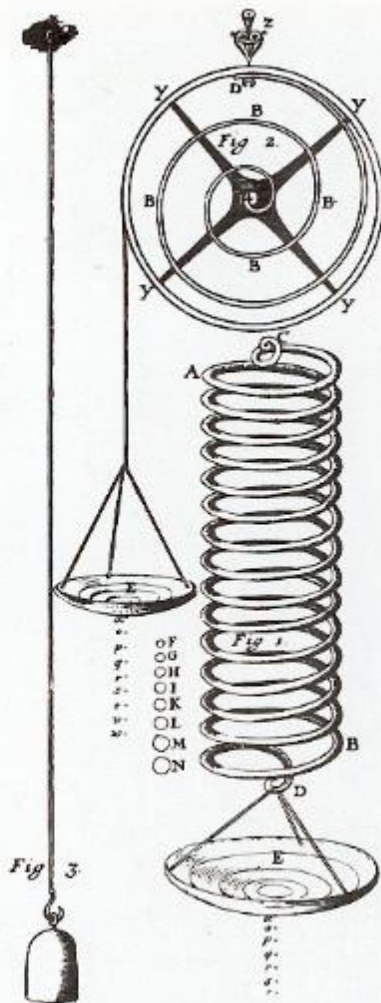
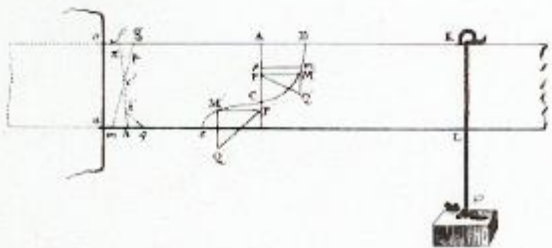
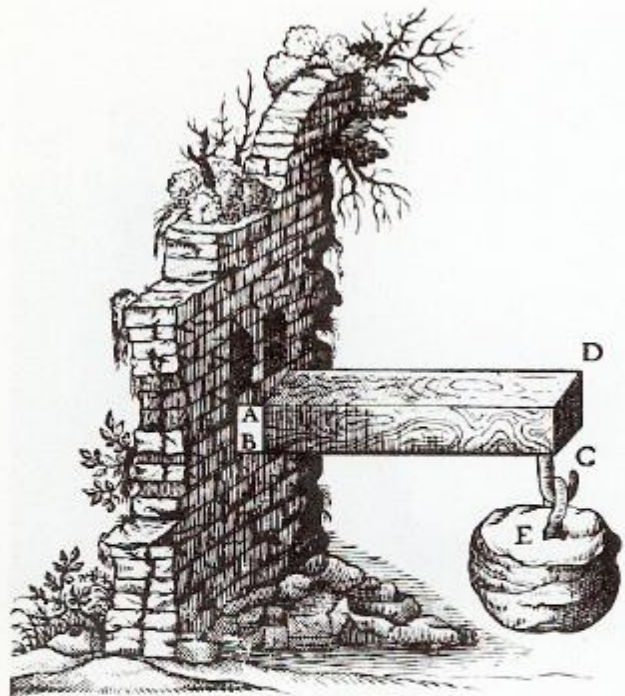




Moment / torque
i.e.

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.

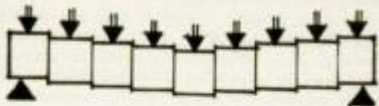
16.10 (left) Studies of elasticity by Hooke.



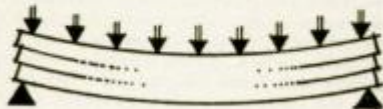
Light interference patterns showing stress in a plastic model beam under polarized light



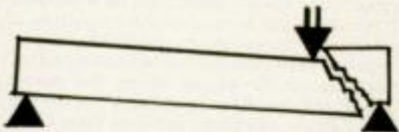
Lines of pressure and tension in a beam



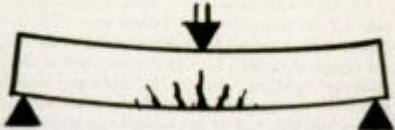
Vertical shear in a beam



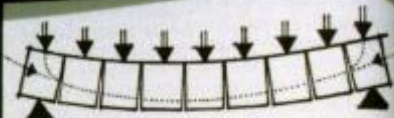
Horizontal shear in a beam



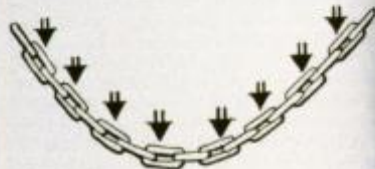
Shear failure near support



Bending failure over two supports



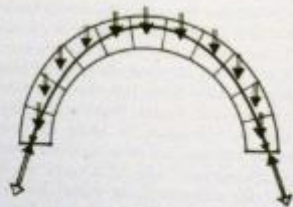
Beam bending and opening of lower surface in tension



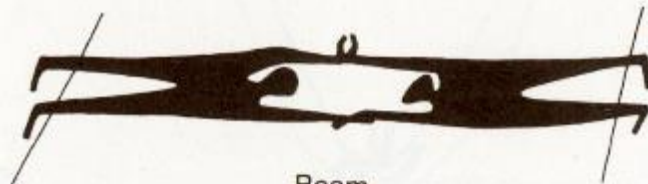
Tensile structure alone: a chain suspended from two supports conforming to line of tension in a catenary curve



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



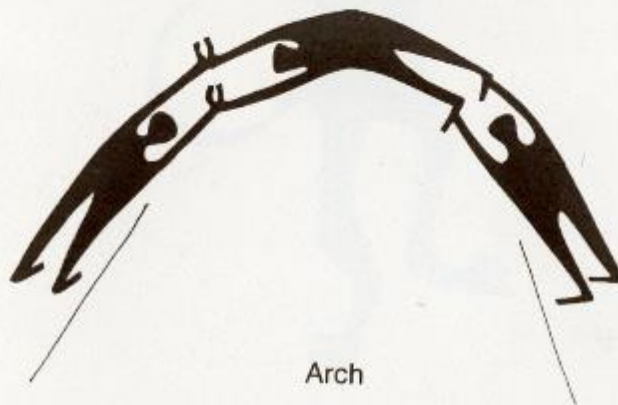
In the semicircular masonry arch the line of pressure does not conform to the shape of the arch and therefore the crown tends to fall while the sides buckle out.



Beam

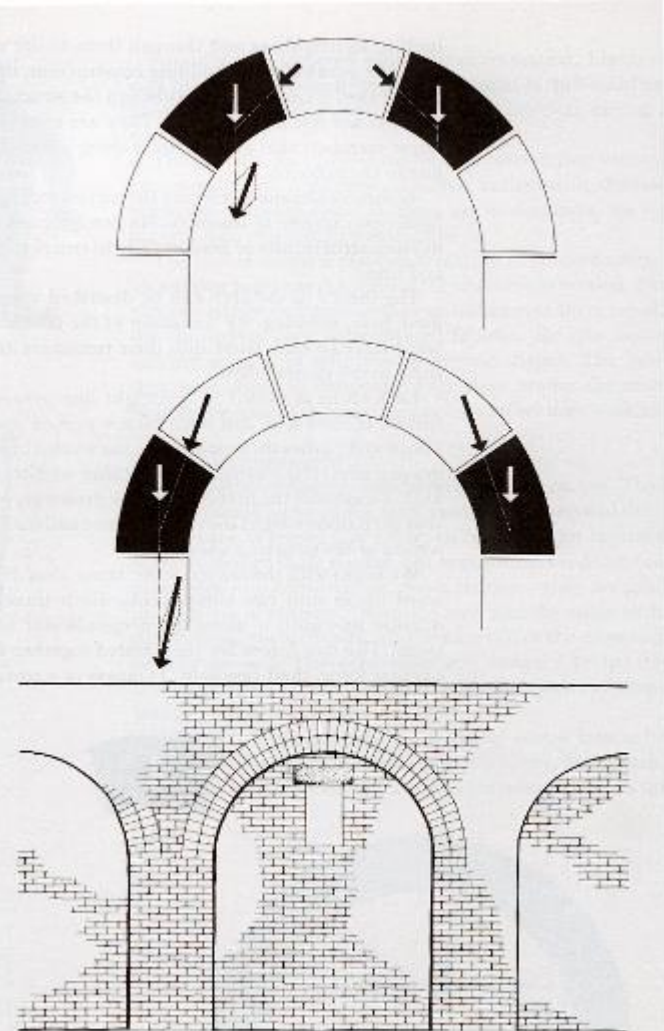
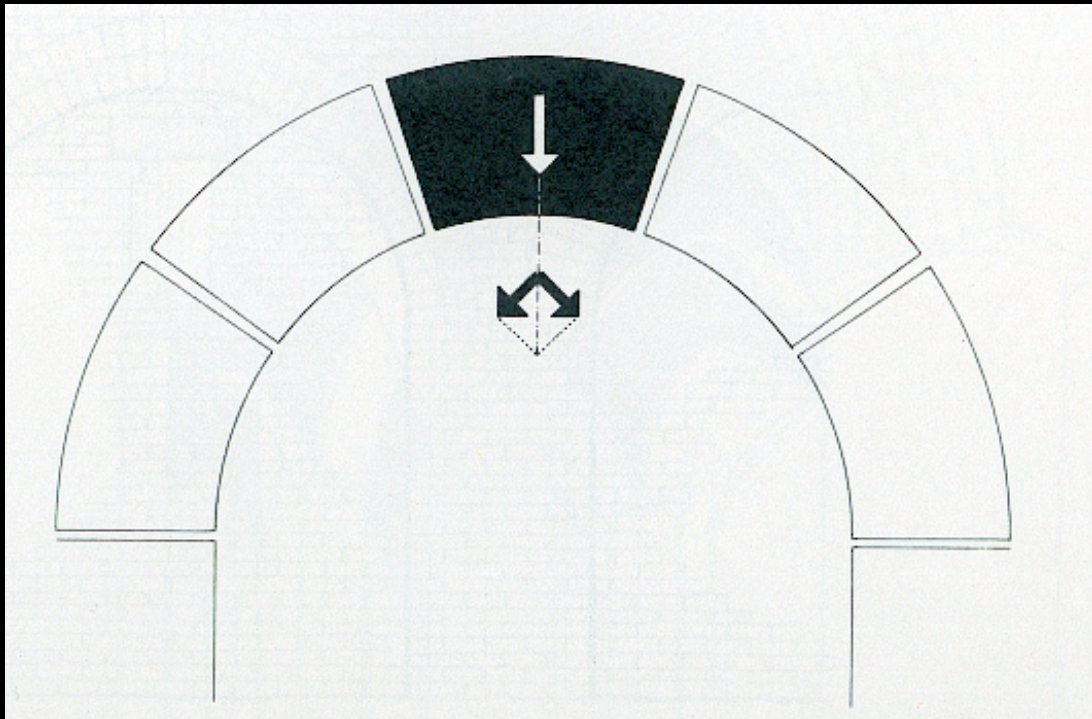


Cable

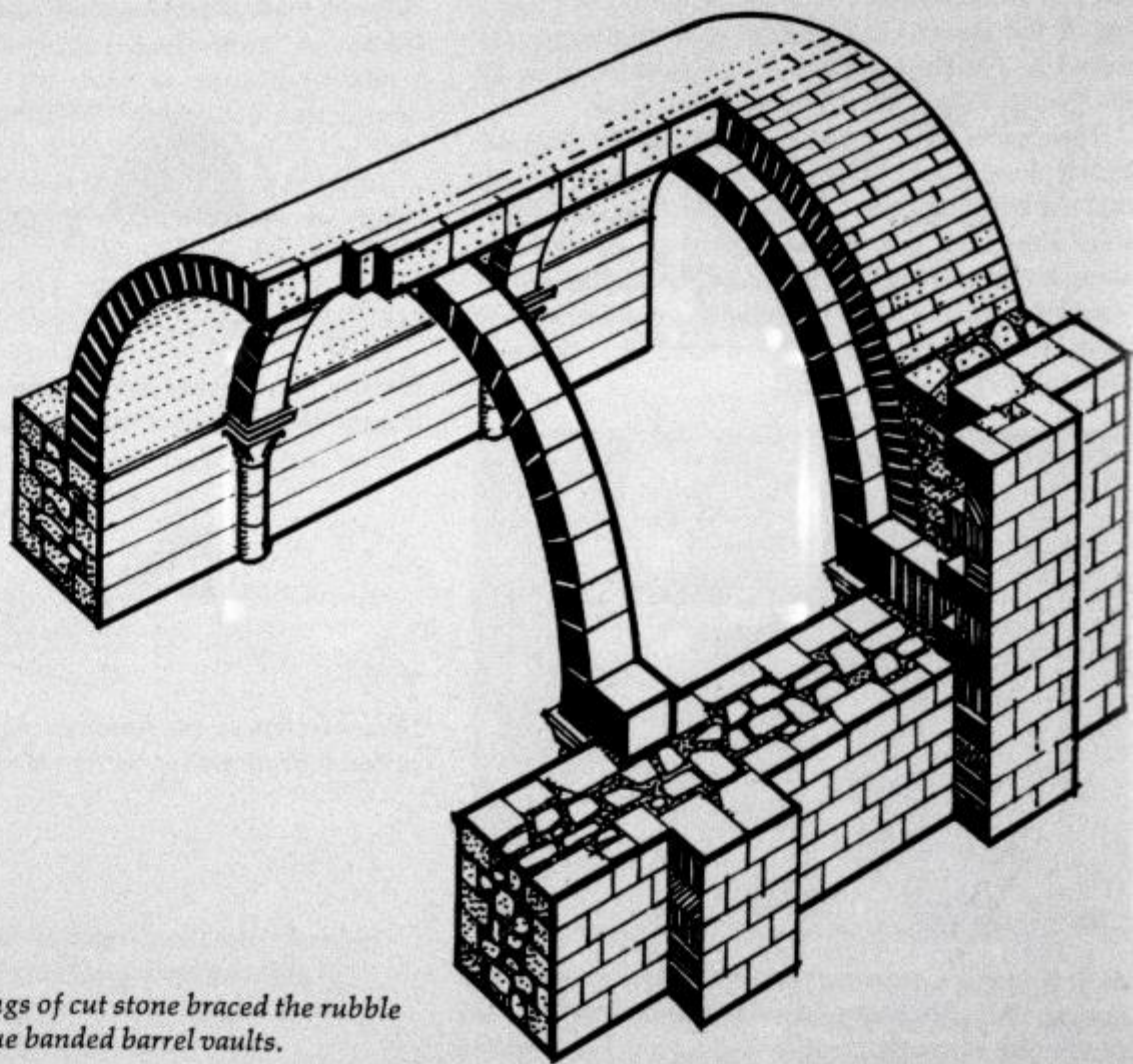


Arch

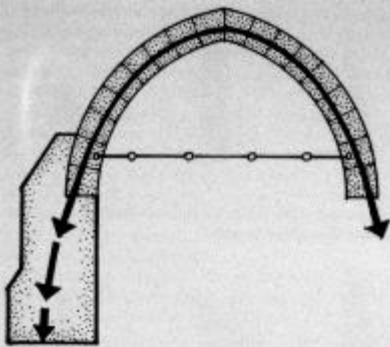
Using the Arch to span



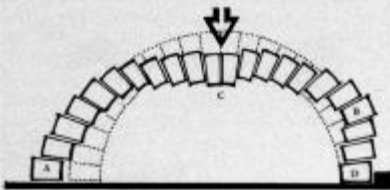
A BARREL VAULT is essentially a row of semi circular arches sitting so tightly in a row as to make a continuous, linear arched space (room)



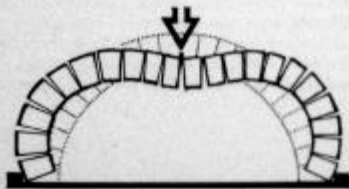
Transverse arch rings of cut stone braced the rubble shell in Romanesque banded barrel vaults.



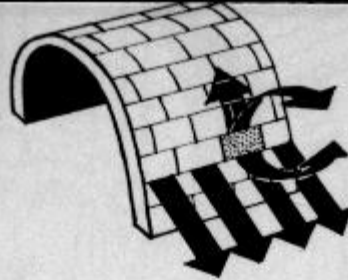
Though the pointed Gothic arch better fits the ideal line of pressure, if too acutely pointed the crown tends to rise while the sides fall inwards. (Similar to saddle failure in pointed corbel vaults)



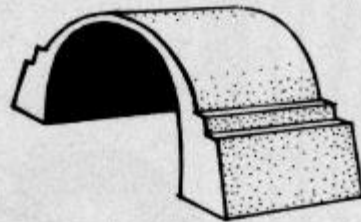
In a semicircular arch where the stones can slide the crown c will fall while the sides a are pressed out above a secure springing b or at the springing itself a.



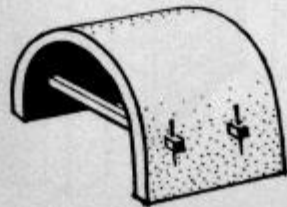
More normal is the rotational deflection of the stones during failure.



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.

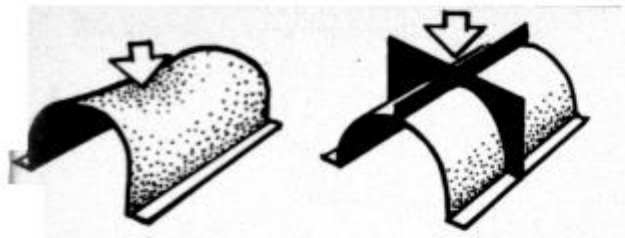
BUTTRESS

A projecting support of stone or brick against a wall

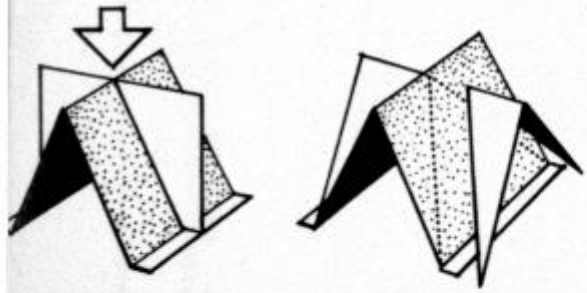
A GROIN VAULT or groined vault (also sometimes known as a double barrel vault or cross vault) is produced by the intersection at right angles of two barrel vaults.

The word "groin" refers to the edge between the intersecting vaults.

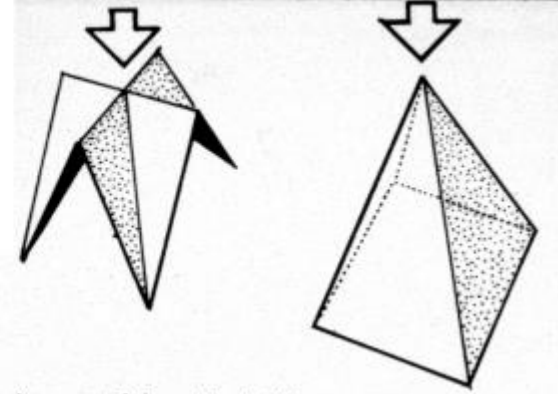
The arches may be round (Roman) or pointed (Gothic).



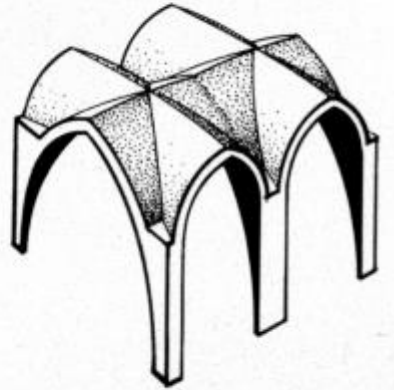
Thin cylindrical barrel vaults fail when the crown falls, pushing out the sides. Thin stiffening plates can reduce this flexure.



Wedge-shaped panels along the crown can replace the longitudinal stiffener. Folded ridges set transversely can brace the sides.

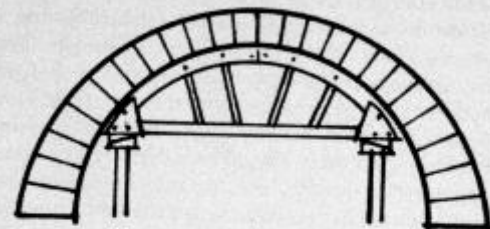


A pyramidal roof is rigid but requires support below the sides. The cross-ridged roof can rest on four isolated supports, channeling loads down the folded groins.

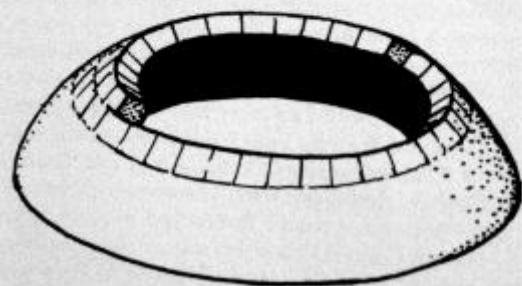


In the pointed Gothic cross vault the panels of vaulting were curved to wedge into position.

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.

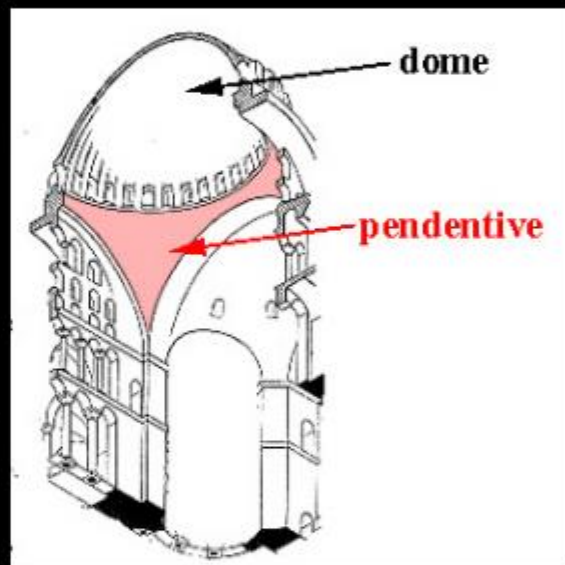


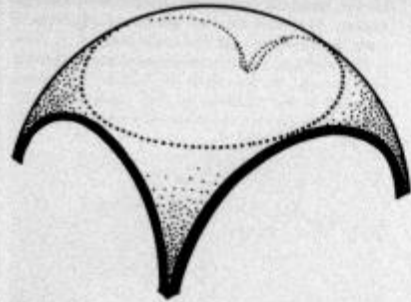
Each ring of masonry in a dome is a structurally stable compression ring.



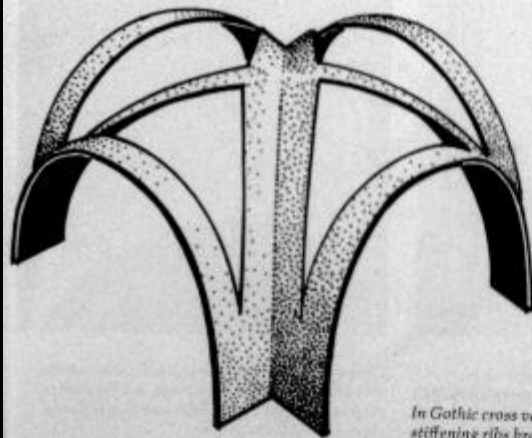
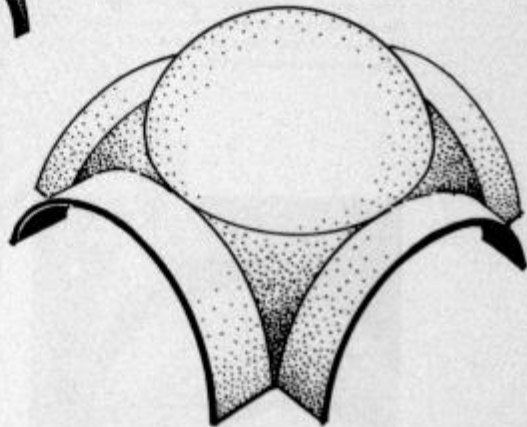
This is what it feels like to be a dome.

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.

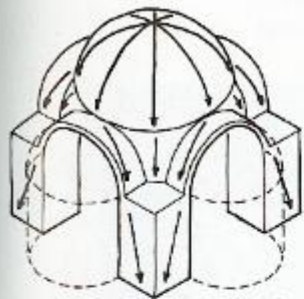




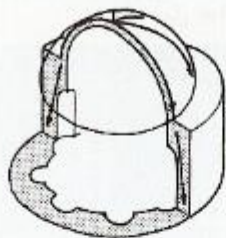
In domes on pendentives the mason could rely on the stiffness of doubly curved surfaces.



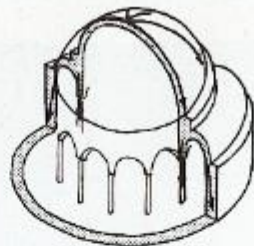
In Gothic cross vaults the folds at the groins acted as stiffening ribs bracing the entire fabric.



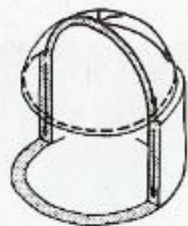
a



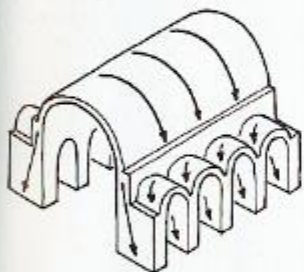
b



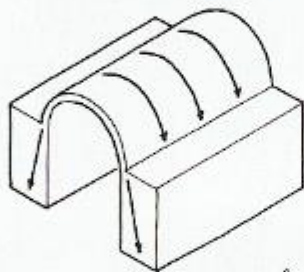
c



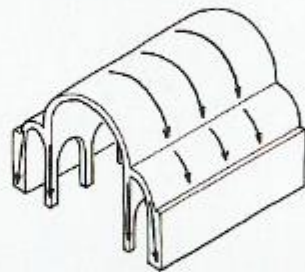
d



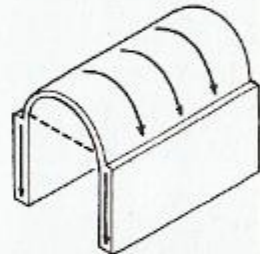
e



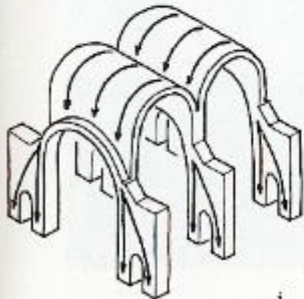
f



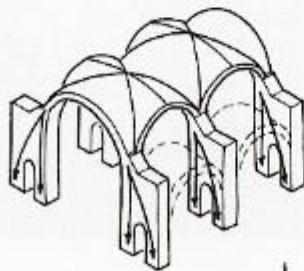
g



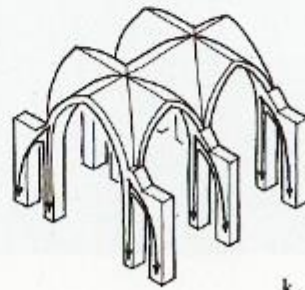
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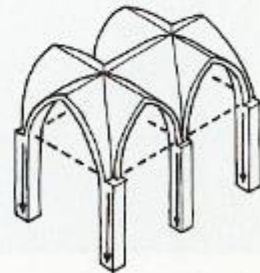
i



j



k



l

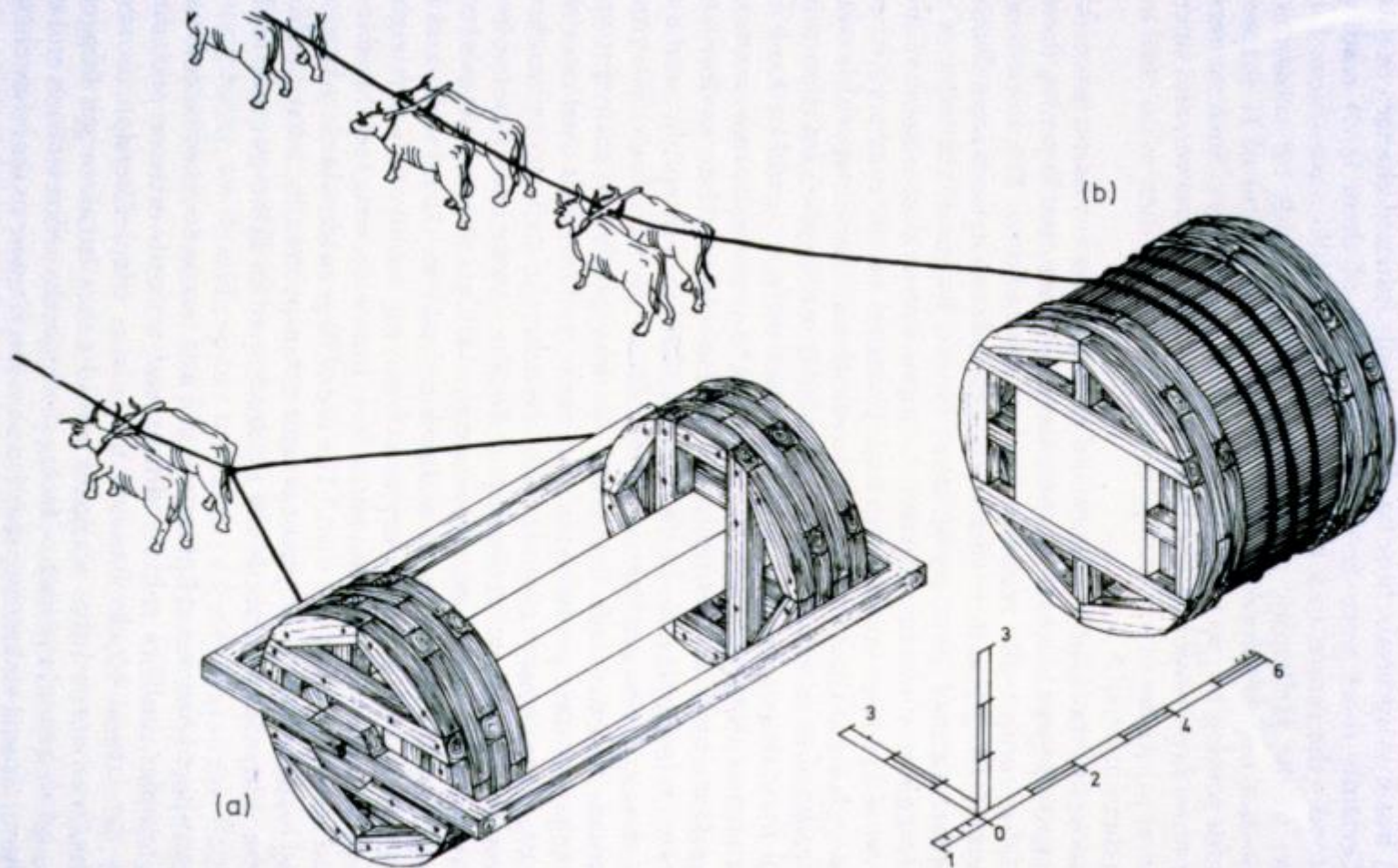
a COLUMN is a freestanding support

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)

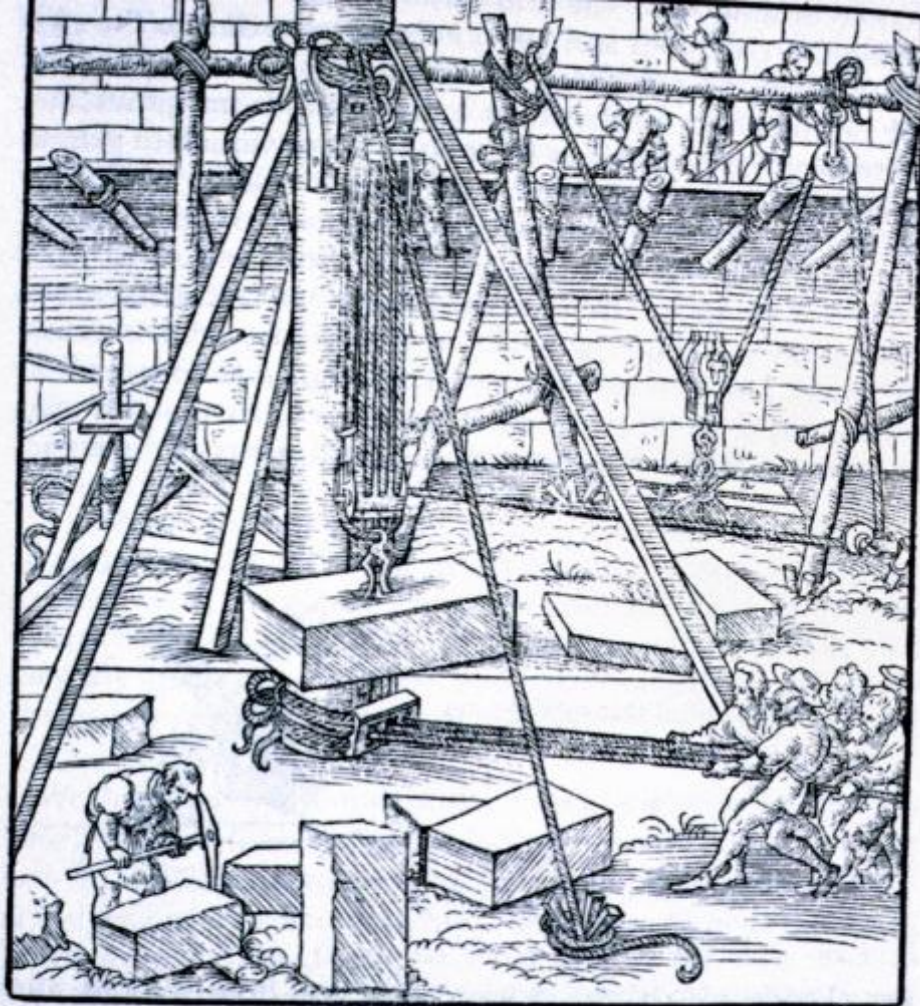
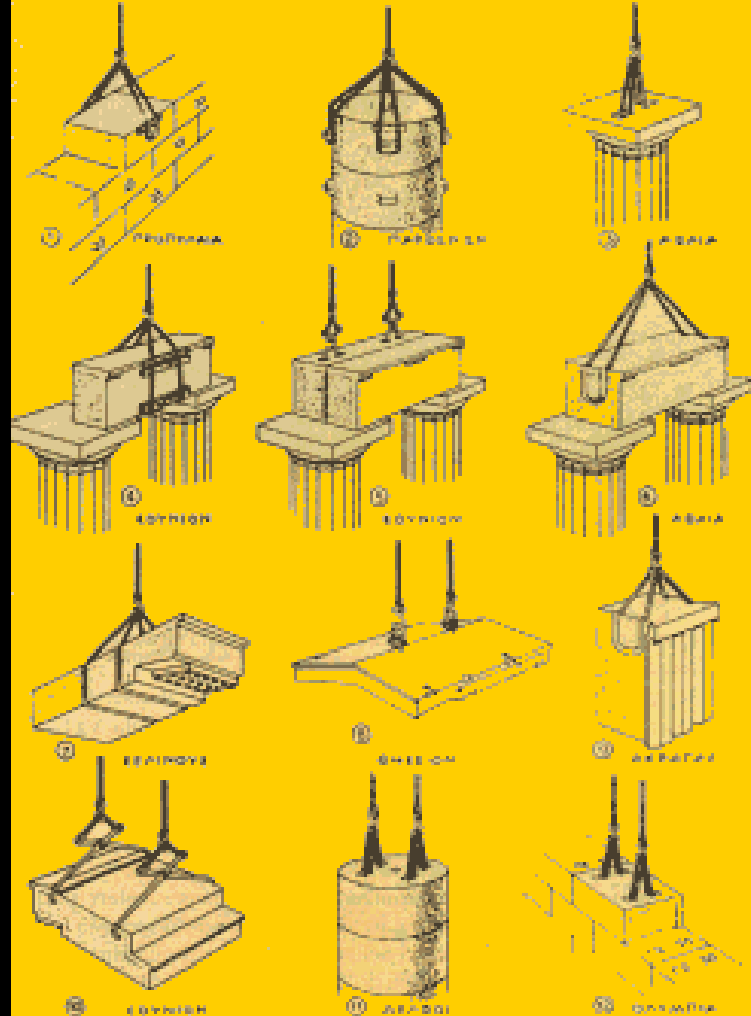
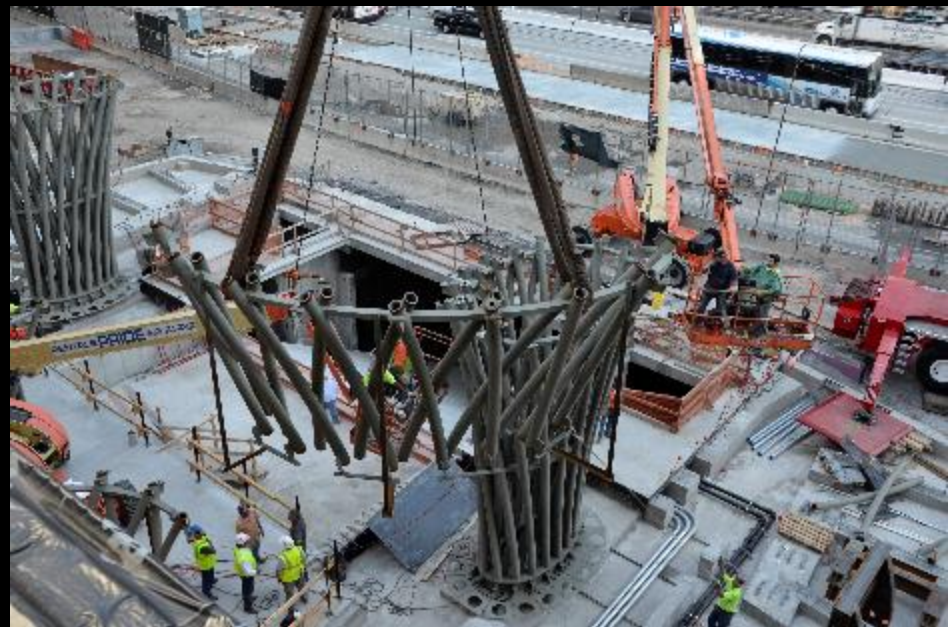


Fig. 139. Levering machinery



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









BAI CRANE

5 AV

STOP CH

Why?

Why
Not?

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!

