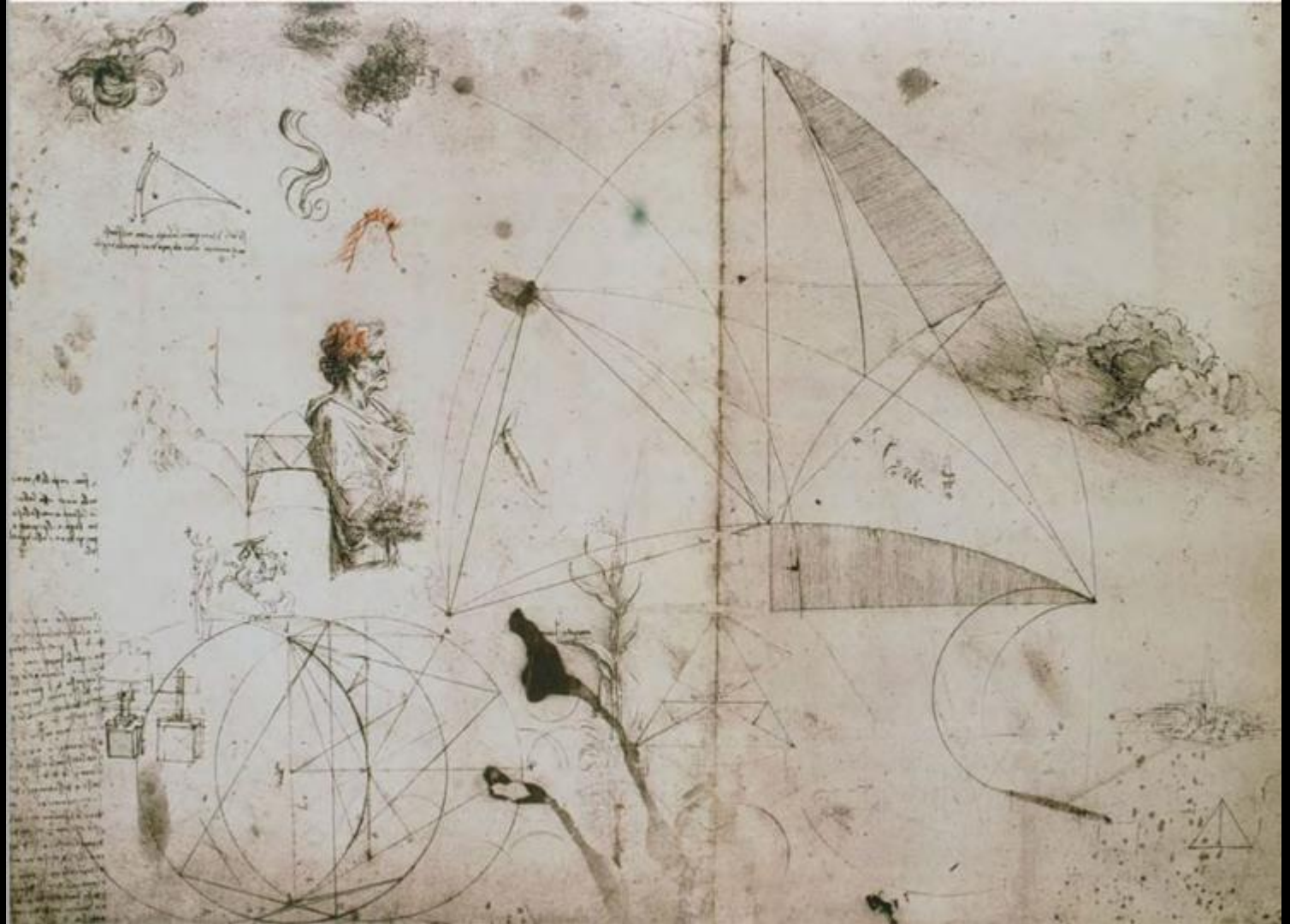
Arch 172: Building Construction 1

Fall 2023

Professor Terri Meyer Boake

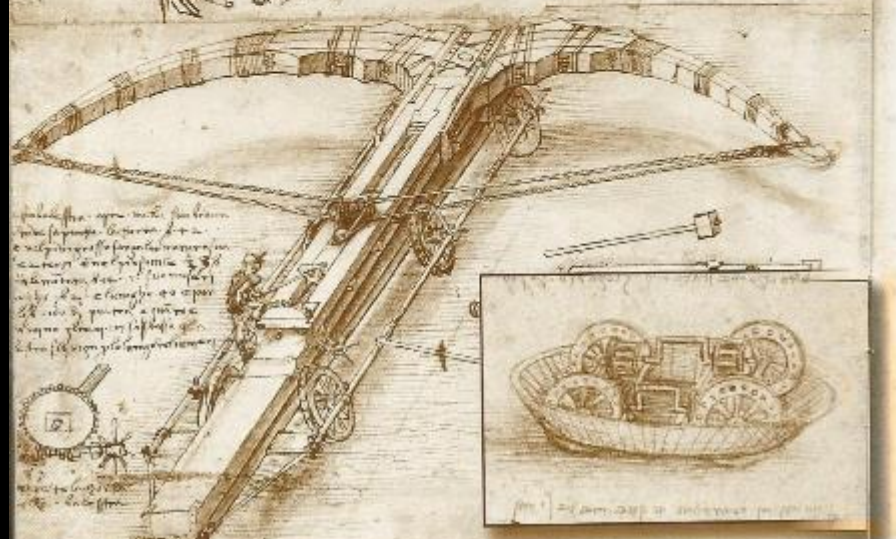
The Sketchbook

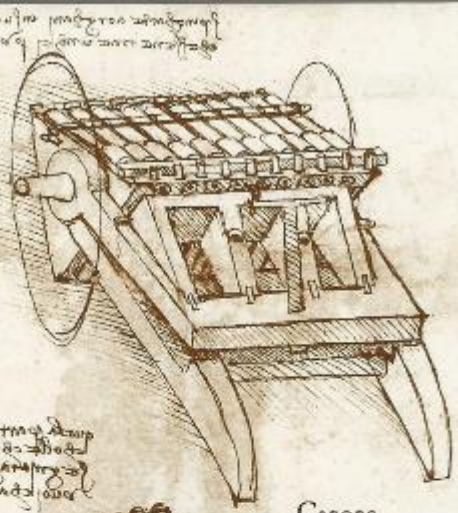


L'ingénieur militaire

Arbalète géante

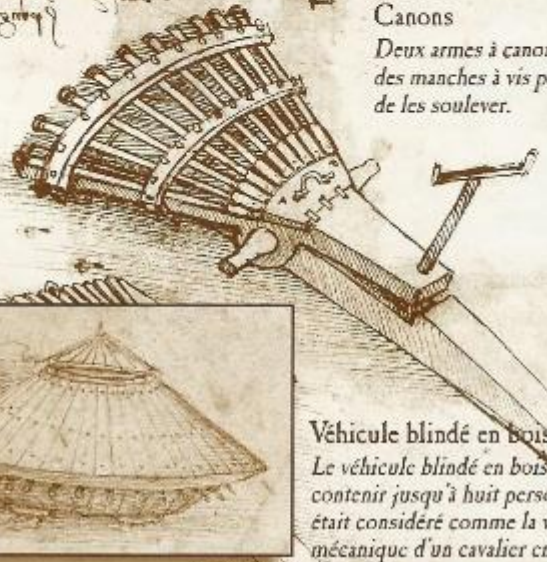
Cette arme effectuait deux actions pour tirer: un coup de marteau relâchait un ressort et un levier redressait l'arbalète.





Canons

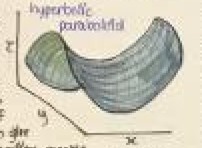
Deux armes à canons avec des manches à vis permettant de les soulever.



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 brought 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 accomodate the increased demands of clients & 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 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 developed by a given deformation and 'strength' the maximum resistance that can be developed. Both can have different values for the same element.

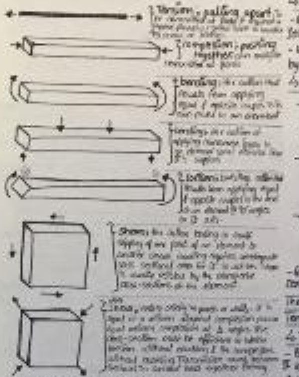
↳ Dynamic & Static Loads

- 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 equalize 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] if the cross-section is 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 element, on whether they respond by bending, rocking, and ability to dissipate energy.

Internal Action

↳ 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 rotation, 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 collinearity in the load will result in bending that will increase the non-collinearity & may lead to buckling.
- Non-collinear tensile load tends to realign the element with the load so that smaller cross-section areas are adequate.
- Transmission of bending requires a joint that resists compression, tension, & shear (and torsion too). (ex: welded joint)

↳ Actions of Human Frame

- skeleton resists 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 torsion when no further rotation is allowed.
- bending (twisting) are resisted by the whole frame.
- To maintain static balance, the body often adjusts its stance or adjusts the magnitude of the internal tension & compression.

↳ Actions of the Built Structure

- All subsequent behaviour depends on internal organisation.
- Humans can't easily know how will the structure respond.

Structural Requirements

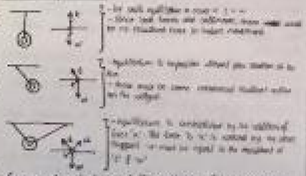
↳ The Basic Geometric Requirement

- In order to form a stable system & not just a loose assemblage, the elements must be adequately joined in a 3-D space [illegible] by the structure for the [illegible] of all likely loading.

↳ 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 at work - static equilibrium.

↳ Static Equilibrium

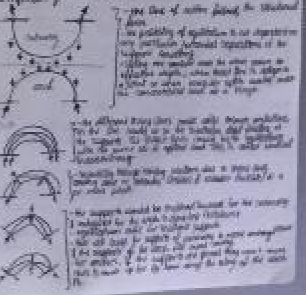


- For a system to be in static equilibrium, it must have a zero linear resultant in every direction, & have no resultant moment.

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

↳ The Catenary & The Arch

- Both are unstable structures. The arch would fall to the ground if loaded & the catenary would merely change its shape to the position necessary to self-equilibrating whereas the [illegible] [illegible] is not. this defect is overcome by an appreciable depth to the [illegible] & their [illegible] faces.
- Since [illegible] [illegible] many [illegible], it may [illegible] if the [illegible] of the [illegible] of the joints [illegible] with [illegible] of some of the [illegible].
- The [illegible] internal forces will be [illegible] over the [illegible], all the cross-sections of either the catenary or the arch, [illegible] will be [illegible] [illegible] to single concentrated tensions or compressions.



HISTORY OF WOOD

Wood is pretty good in tension and bending; resilient under repeated loads
↳ trees are continually flexing & they hold their strength

Wood Construction Structural Types:

- heavy bearing wall (solid)
- post and beam
- light framing → more so residential construction (unique to wood construction)

Advantages of wood:

- natural material
- renewable (if carefully managed)
- sequesters carbon → helps with greenhouse gases
- easily worked with hand tools on site

Disadvantages of wood:

- burns - rots
- food for termites and carpenter ants
- not available everywhere
- height limited (related to burning, maximum in Canada is 6 storeys)
- natural insulator so cannot store heat
  - ↳ materials like stone are thermomass materials meaning they absorb heat

History:

- 1st timber house in Britain (mesolithic period)
- Neolithic long house during 4000 B.C.E.
- tools made of wood, then adding metal (iron/copper); metal saw
- Iron age: wooden molds used to shape clay, adobe etc.
- increase in wood precision (metal/steel improved tools), Egypt had to gather every bit of wood to build the pyramids
- at this time, woodlands were cleared dramatically (50%)
- invented timber crane
- Middle Ages: carpenters were sought out
  - water mills were invented (could cut/manufacture materials)
  - Westminster hall, temples in China
- 21st Century: in N.A. wood extremely plentiful

Historic Wood Architecture of Japan

- cedar wood; distinct to Japan (smooth and fine-grain texture)
- oldest known temple, pagoda, 1300, made of cedar

THE INTRINSIC CONNECTION BETWEEN ARCHITECTURAL DESIGN AND STRUCTURAL MATERIALITY

INTRO LECTURE [illegible]

THE PYRAMIDS OF GIZA
[illegible]
2560 BC
- the ability of a material to withstand force is its most important attribute
- made of stone (compression material)

THE PARTHENON, GREECE
[illegible]
432 BC
- also made of stone
- [illegible]

THE ROMAN COLOSSEUM
ROME, ITALY
[illegible]
80 AD
- the Romans invented the arch

THE PANTHEON
ROME, ITALY
[illegible]
126 AD
- [illegible]
- [illegible]

SANTA MARIA DEL FIORE
FLORENCE, ITALY
[illegible]
1436
- dome
- [illegible]

NOTRE DAME DE PARIS
- gothic architecture
- focused on getting light into the building [illegible]

SAINTE GENEVIÈVE LIBRARY
- stone perimeter
- [illegible]

INDUSTRIAL REVOLUTION
- steel [illegible]

THE EIFFEL TOWER
PARIS, FRANCE
- [illegible]
- [illegible]

BROOKLYN BRIDGE
NEW YORK CITY
JOHN ROEBLING
1883
- stone piers
- [illegible]

[illegible]
- [illegible]
- [illegible]

[illegible]
- [illegible]
- [illegible]

[illegible]
- [illegible]

[illegible]
- [illegible]

Stone: From Technique to Technology

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

Aesthetics

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

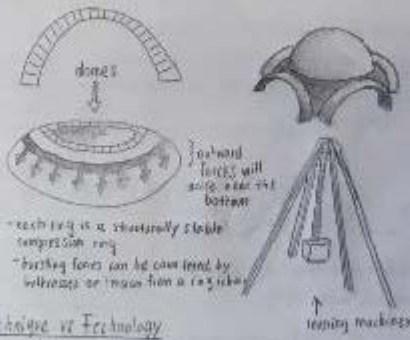
Stone:

- natural material
+ great for compression
- some stones are better for construction e.g. sandstone is very brittle/cracks easily
- stone gets destroyed by pyrenes
- water imparts materials, mass and tubers 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 B.C.E, 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: used ramps to move heavy objects (stones)

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

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

Pyramids of Giza

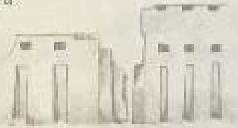
Khufu/Cheops, Khafre/Chephren and Menkaure)
2580 B.C.E.

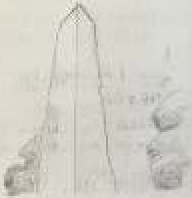
- tomb sits at the bottom of the pyramid
- grave robbers stole a lot of riches from vaults
- the finished stone were smooth; still them looking very rough and coarse

Temple at Karthnak

Thebes, Egypt 1350 B.C.E.

- temple that was used while the pharaoh was alive ; not a tomb
- dedicated to the deity that the pharaoh worshipped
- goal was to impress
- many columns - spaced as far as stone can span
- hypostyle hall : where the roof is supported by a vertical row of columns

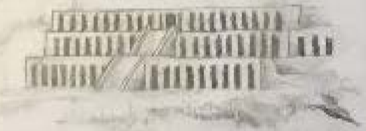




Mortuary Temple of Hatshepsut

Valley of the Queens, Egypt 1473 B.C.E.

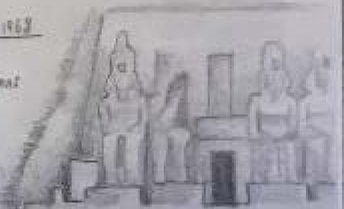
- simpler style
- covered ramp/stone along with sizes, more expensive stone (facade)
- hieroglyphs were sometimes painted
- very colourful and painted, that has worn away over the many years



Abu Simbel, Pharaoh Ramesses II

Aswan Egypt, 13th Century B.C.E - relocated in 1968

- two complex cut into the cliff
- interior was a modified hypostyle hall - less columns
- more interior space
- columns were statues , painted very colourfully



Tomb of Ramesses IV

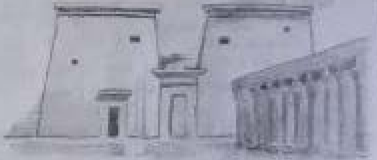
Valley of the Kings 1155 B.C.E

- intentionally hidden in desert

The Temple of Isis at Philae

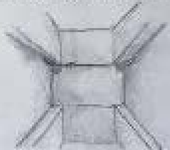
Aswan, Egypt 380 B.C.E

- many carved capitals, human figures & nature (lotus leaves)
- each capital is inconsistent
- materials (stone) seriously restricts the ability for them to span
- they had no wood because no trees

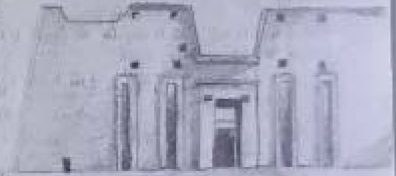


The Temple of Horus at Edfu

Edfu, Egypt, Ptolemaic Kingdom 237 B.C.E



- colonnade (row of columns) lots of symmetry
- all interior spaces were for ceremonies etc.
- column capitals similar to the temple at Philae
- spacing between the columns are small
- stone planks on top to make the ceiling
- space is dense, heavy, and full of columns
- columns surround a courtyard
- contains hypostyle hall



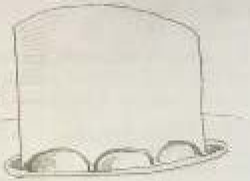
MIT Chapel

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" [illegible]
- interior brick design pattern is different from exterior

MIT Chapel



Rothko Chapel

Houston, Texas (1971)

Philip Johnson

- extremely simple and reflective of modern movement
- [illegible] [illegible] / [illegible] roof made [illegible]

Philips Exeter Academy Library

Exeter, New Hampshire (1972)

Louis I. Khan

- modern, regular [illegible] ("[illegible]") symmetrical
- [illegible] in the design
- exterior is brick, interior [illegible] concrete
- large, open space + galleries

Phillips Exeter Library

Palmer Museum of Art

Penn State University, State College, Pennsylvania (1990)

Charles W. Moore

- "post modern"
- revival of classical architecture [illegible]
- arches, [illegible], [illegible] ([illegible] [illegible] [illegible] and [illegible])
- symmetry and [illegible]
- worked with [illegible] masonry (small brick units are adaptable to different shapes in structure)

Brown College

Rice University, Houston, Texas (1965) (2002)

Michael Graves

- masonry, [illegible] [illegible]
- decorative brick laying
- [illegible] [illegible], [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]
- wooden arches to support ceiling
  - existing building [illegible]; same style with brick

Herring Hall

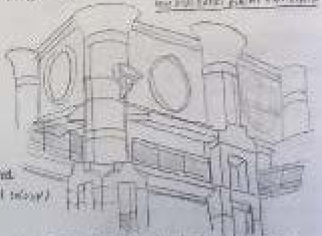
Rice University, Houston, Texas (1984)

Cesar Pelli, Architect

"post modern"

- [illegible] [illegible] of [illegible] [illegible] ([illegible] [illegible])
- [illegible] [illegible], brick patterns
- [illegible]
- [illegible] [illegible] + [illegible] [illegible] [illegible]
- [illegible] [illegible] [illegible]

[illegible] [illegible] [illegible]



Anne and Charles Duncan Hall

Rice University, Houston, Texas (1996)

John Outram Associates

- arches, capitals
- [illegible] brick detailing; some are glazed
- [illegible] interior ([illegible], [illegible] [illegible] [illegible])
- [illegible] [illegible] ceiling

From a stylistic perspective brick has invited an eclectic attitude towards styles and [illegible]

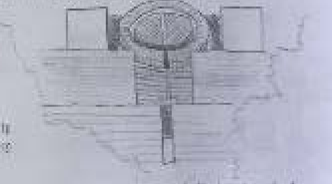
Brick can be made as large precast panels and hung from the building to make a [illegible] [illegible] [illegible] [illegible] at height in [illegible] weather

Museum of Modern Art

San Francisco, California (1995)

Mario Botta

- [illegible], square windows, simplified
- "[illegible]"
- fairly symmetrical
- [illegible] [illegible] [illegible], brick panels
- red brick [illegible] [illegible] in brick panels



Museum of Modern Art [illegible]

Millenium Science Complex

Penn State University, State College, Pennsylvania (2011)

Rafael Viñoly Architects

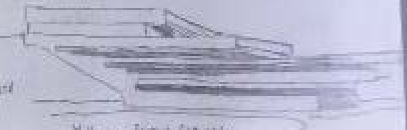
- massive cantilevers
- brick panels that were prefabricated - construction [illegible] easier
- special [illegible] in the underside

Dr. Chau Chak Wing Building

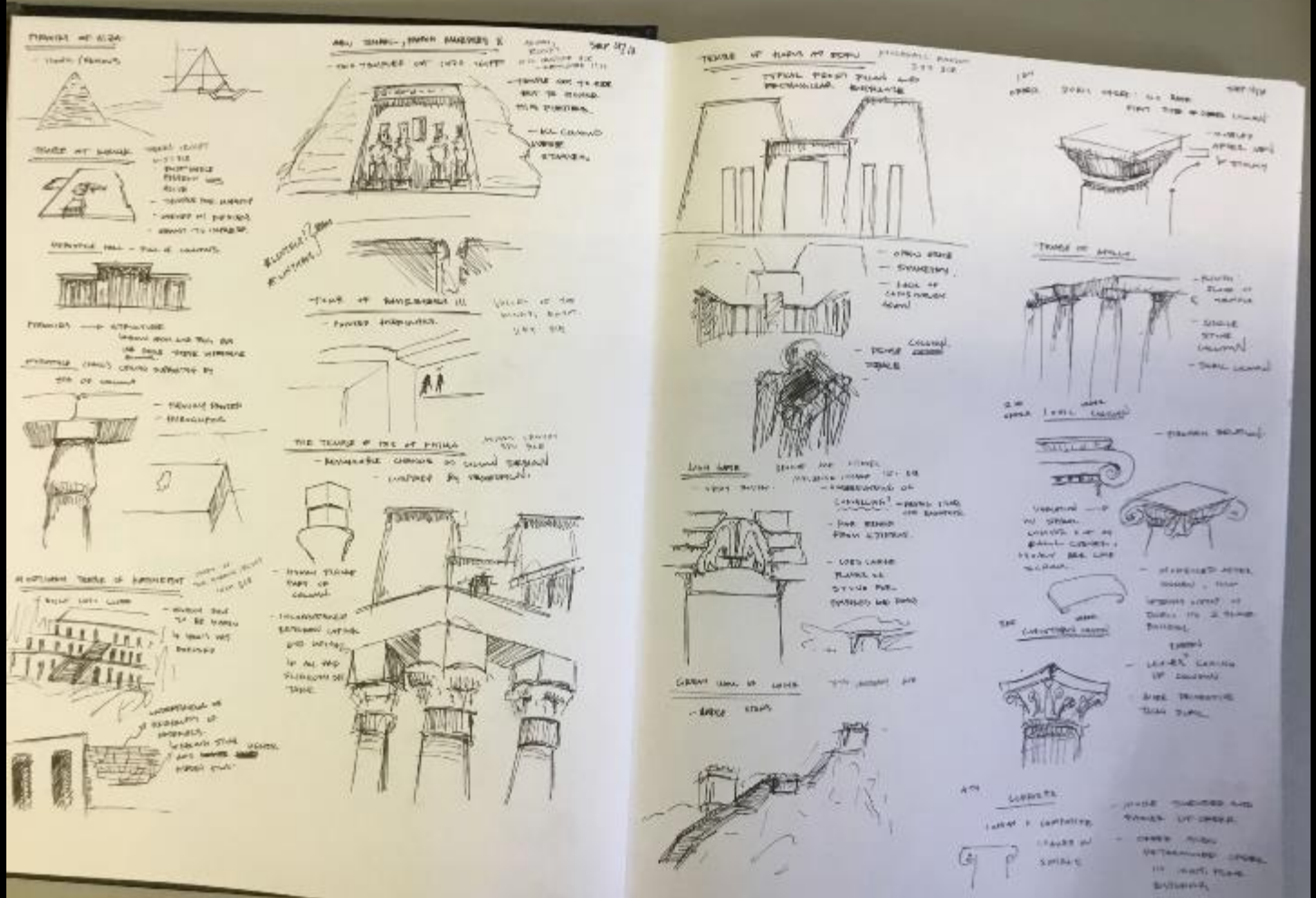
Sydney, Australia (2015)

Frank Gehry

- [illegible] [illegible], [illegible] to [illegible]
- custom prefabricated brick [illegible]



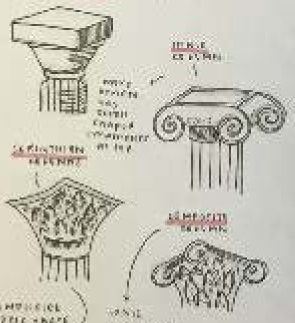
Millenium Science Complex




[THE RENAISSANCE]

CHINA–GREECE

- [illegible]
  - mosaic painted as frescoes
- [illegible]
  - multiple columns + designs
  - inspired by vegetation
  - size limited by ability of material to span
  - all temples had a different take/individuality?
- [illegible] at Karnak, 1??? BCE
  - formalized open space
  - surrounded by columns (peristyle)
  - symmetry of space
  - allows light to enter
  - space is dense, no. of columns
- [illegible] 1??? BCE
  - limestone
  - smoother lines
  - fortification (thick)
  - corbelling (support structure like an arch or balcony)
- [illegible] 7th century BCE
  - steel + stone
- Order of columns → [DORIC] order
  - columns → not different visibly in Egypt
  - similar inside temple
  - reflecting off human body
- [illegible]
  - columns carved in one piece
  - Greeks added mathematically into their art
- [illegible] circa ??? BCE
- [illegible] ??? BCE
  - different capitals
  - colonnade around perimeter
- [illegible] Athens
  - six columns, carved as humans to hold up porch
- [illegible] (Greece)
  - huge columns, mainly
- [illegible] (Italy)
  - typical temple architecture
- [illegible] 497 BCE
  - style of architecture more refined
- the classical style → used Roman arches
- [illegible]
  - promenade around arches
- [illegible] Italy
  - walls plastered over
  - originally coloured



the building: work

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 (due east/west) 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 exactly 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 days in winter

The Summer Solstice

- occurs when the sun rays are at their highest 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 summer 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 penetrated by the radiation at each time of day

The Sketches

Architects do sketches all through the design process.

Most are "quick and dirty"

Unless you become super famous, nobody will ever want to frame them and they won't get given to your grandmother for her birthday.

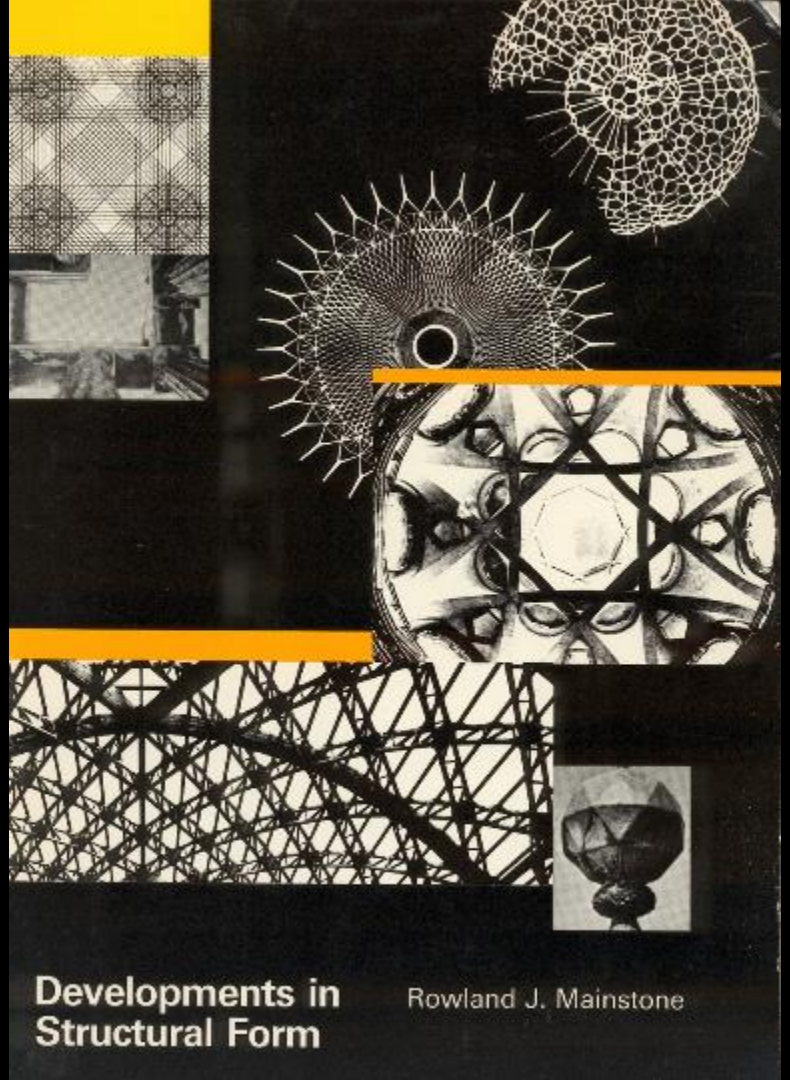
Architectural sketches are mostly lines, no shading

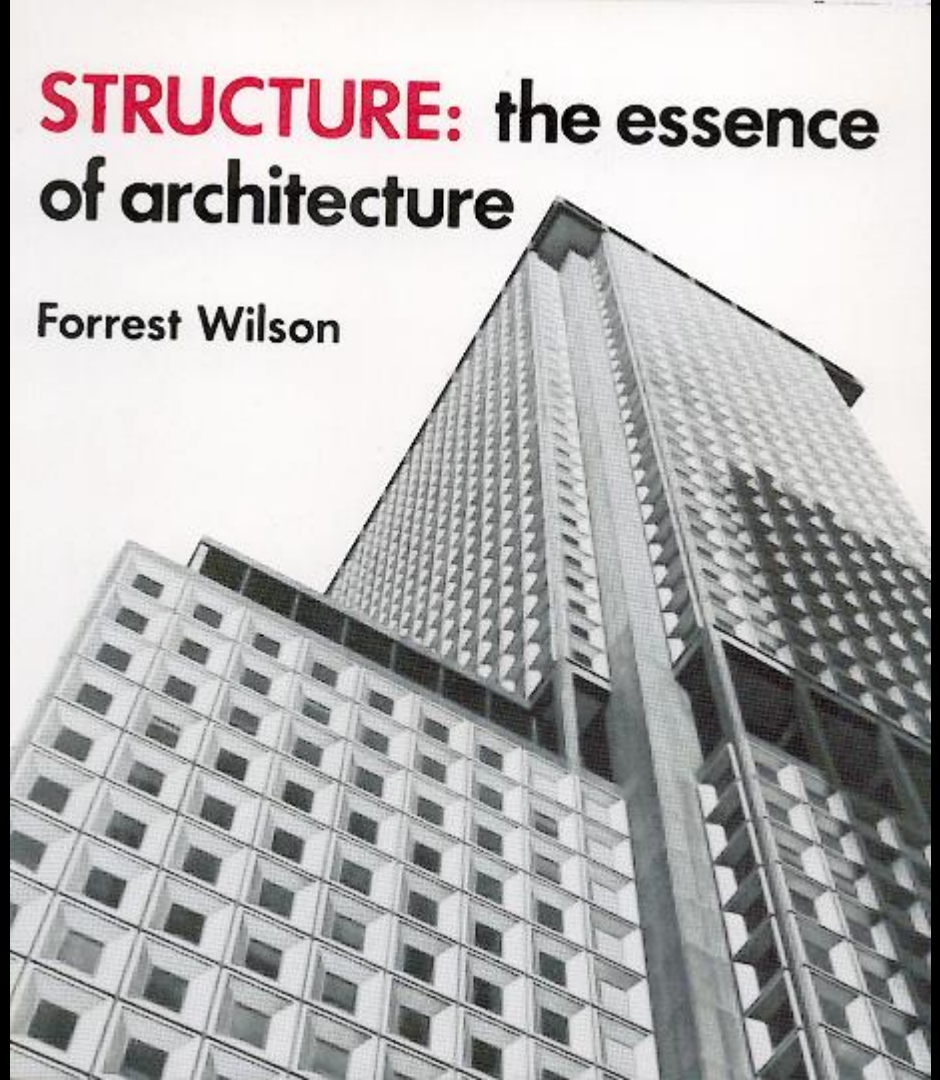
Hatch is used sparingly to create depth.

The lines are all hand drawn, pretty straight, but with a bit of attitude

Check out my Pinterest board for some good examples

https://www.pinterest.ca/terriboake/architecture-sketches/

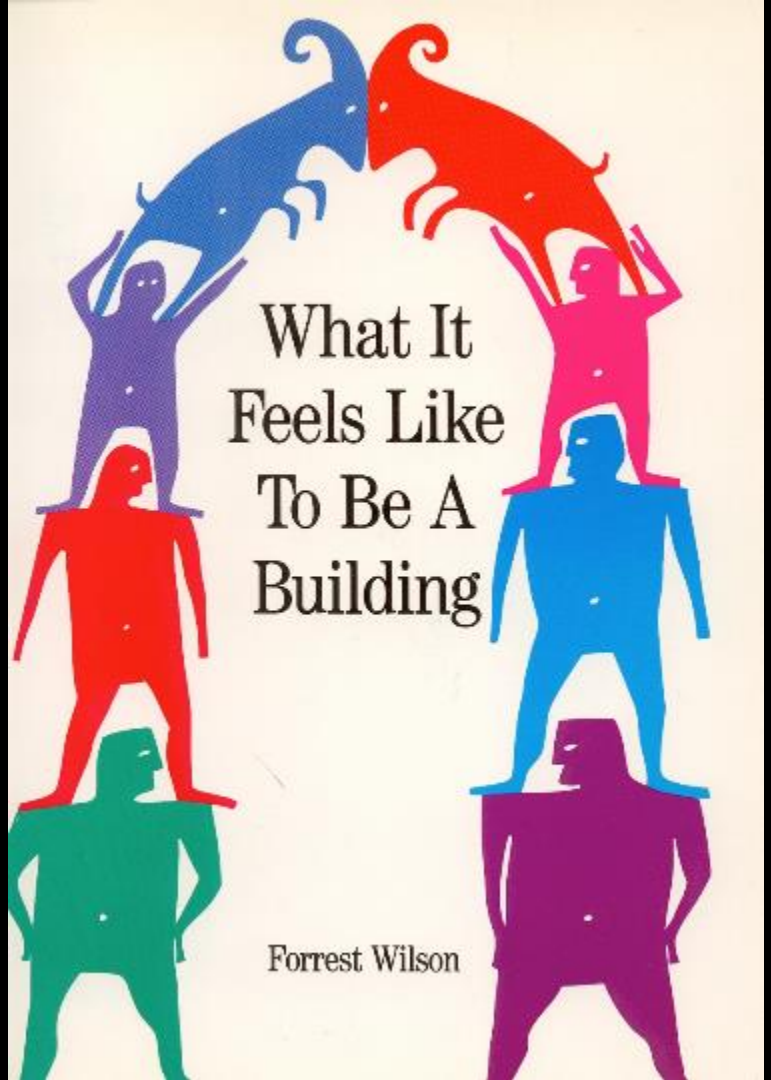

Developments in
Structural Form
Rowland J. Mainstone

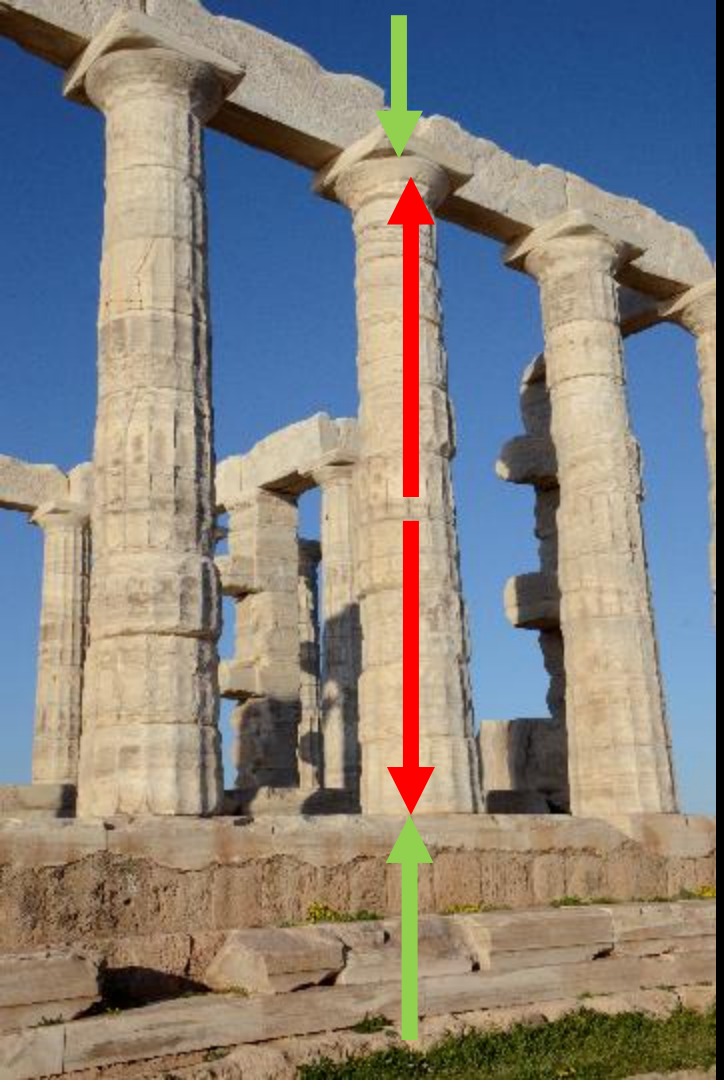

STRUCTURE: the essence
of architecture
Forrest Wilson

Stone: From Technique to Technology

Part One:
From Antiquity to the Romans

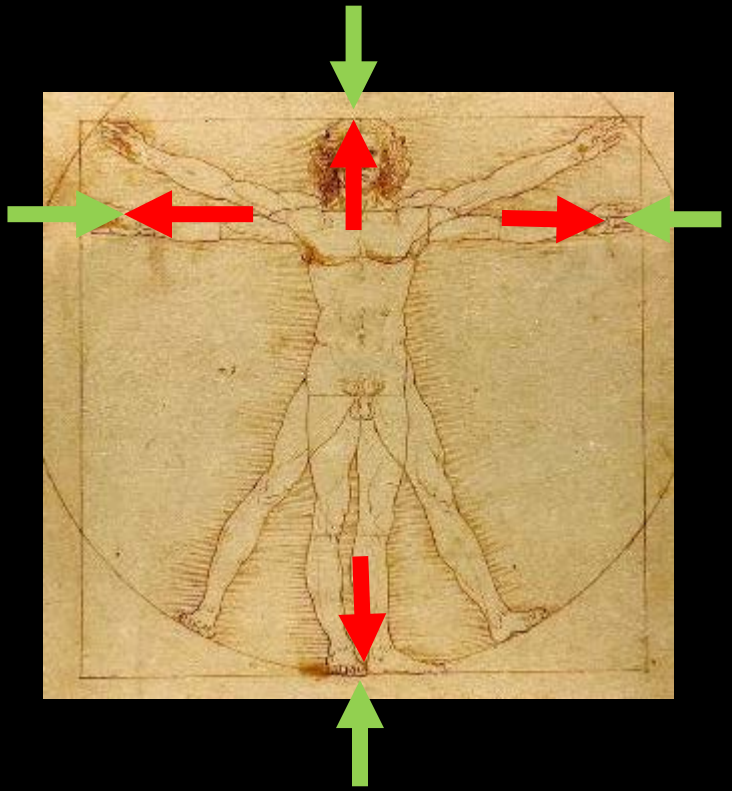
forces


What It
Feels Like
To Be A
Building
Forrest Wilson



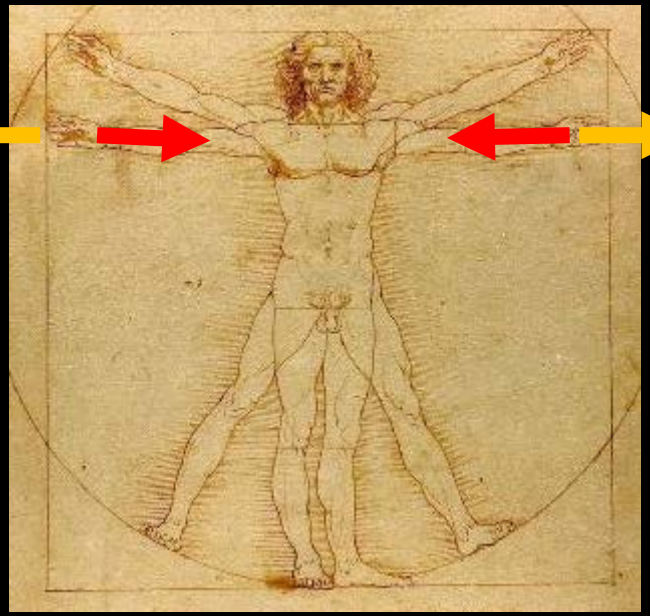
Compression
i.e.

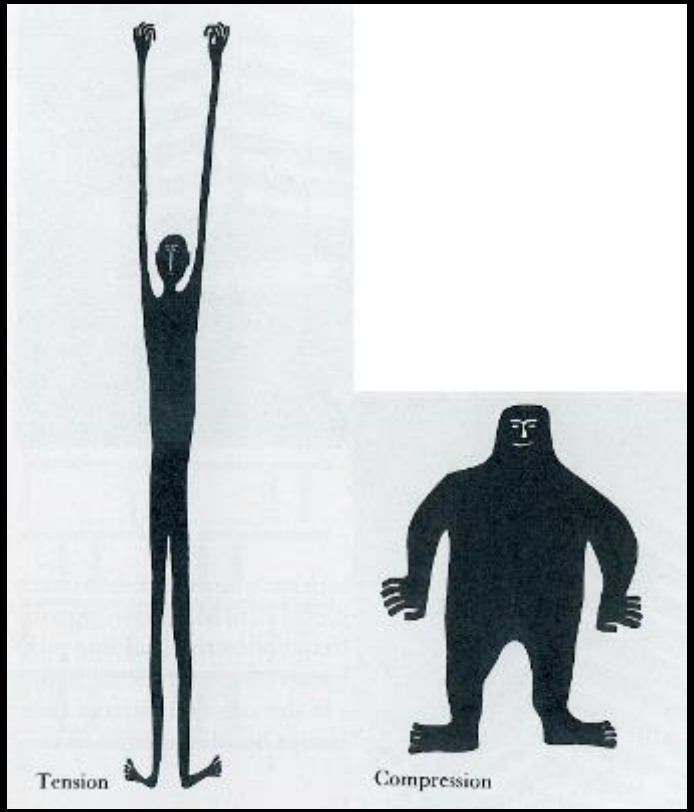
CRUSHING



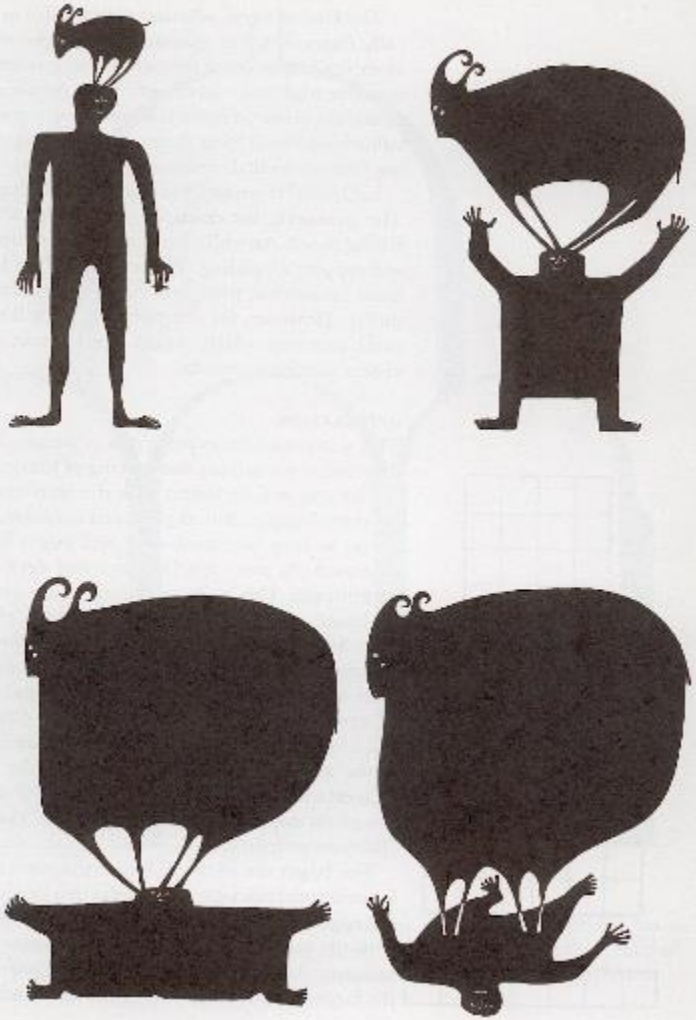
Tension
i.e.

STRETCHING



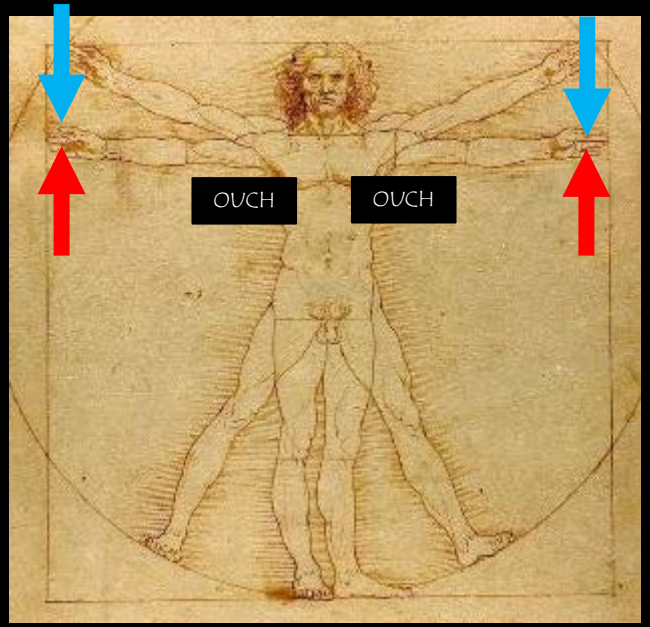

Tension
Compression

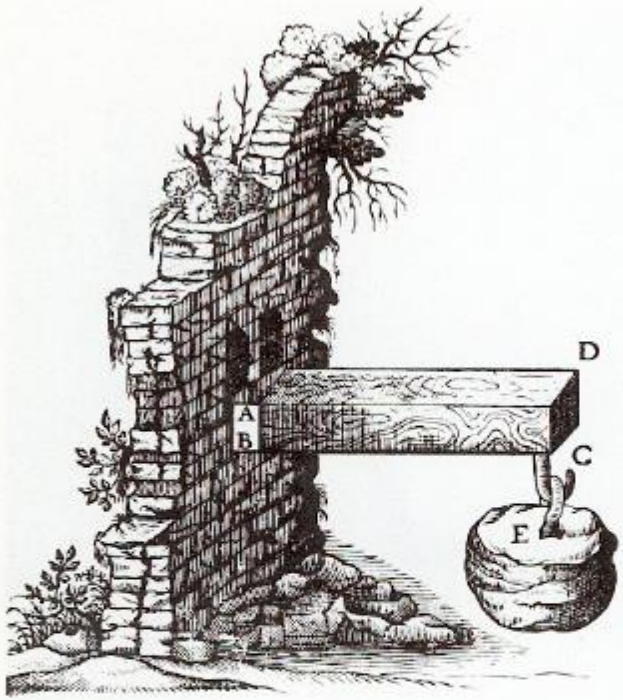

Push
Pull

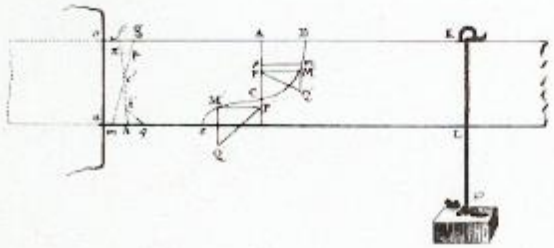


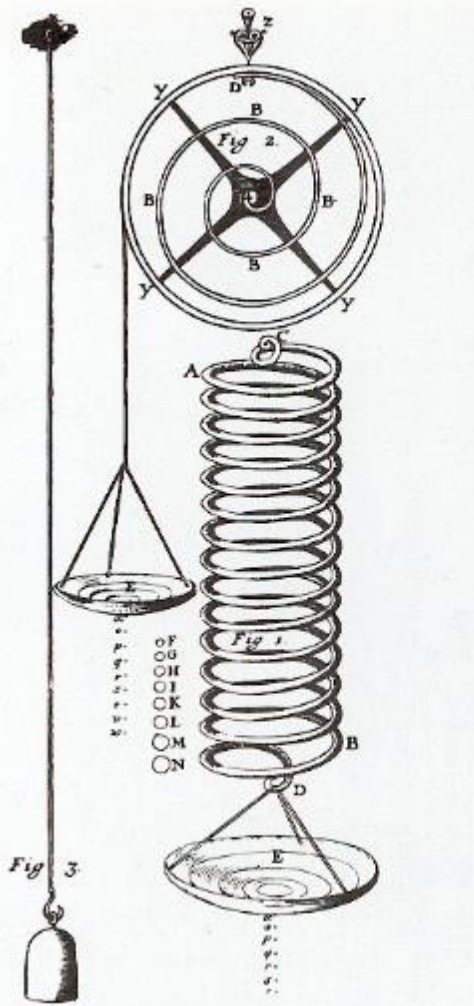
Moment / torque
i.e.

BENDING





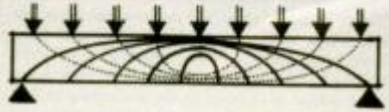




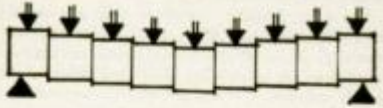
16.9 (*far left*) Studies of the behaviour of a cantilever beam by Galileo (top) and Coulomb (bottom). Galileo assumed that rotation would occur around the bottom edge at B. Coulomb more correctly assumed that the internal stresses over the depth of the cross-section would vary continuously from compression 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.

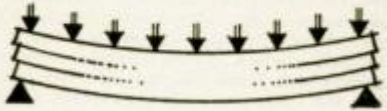
Light interference patterns showing stress in a plastic model beam under polarized light



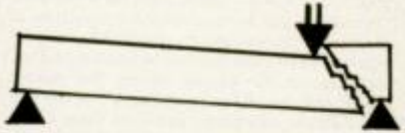
Lines of pressure and tension in a beam



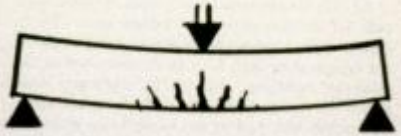
Vertical shear in a beam



Horizontal shear in a beam

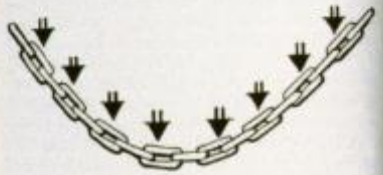


Shear failure near support

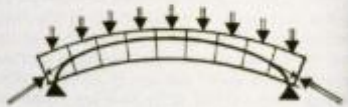


Bending failure over two supports

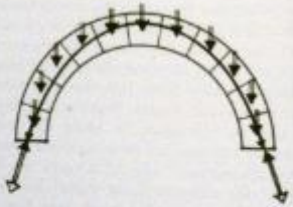
Beam bending and opening of lower surface in tension



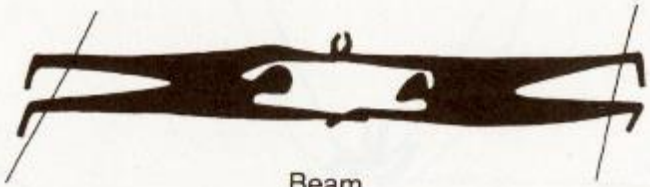
Tensile structure alone: a chain suspended from two supports conforming to line of tension in a catenary curve



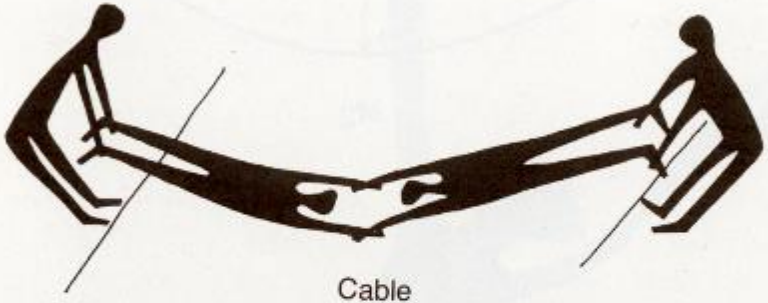
Compression structure alone: a masonry arch wedged into position along line of compression in a reversed catenary curve



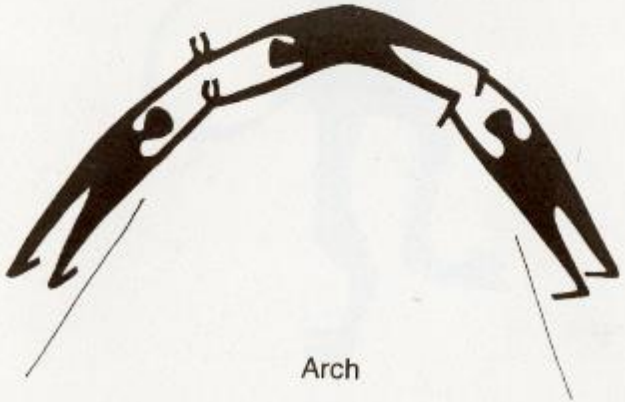
In the semicircular masonry arch the line of pressure does not conform to the shape of the arch and therefore the crown tends to fall while the sides buckle out.



Beam

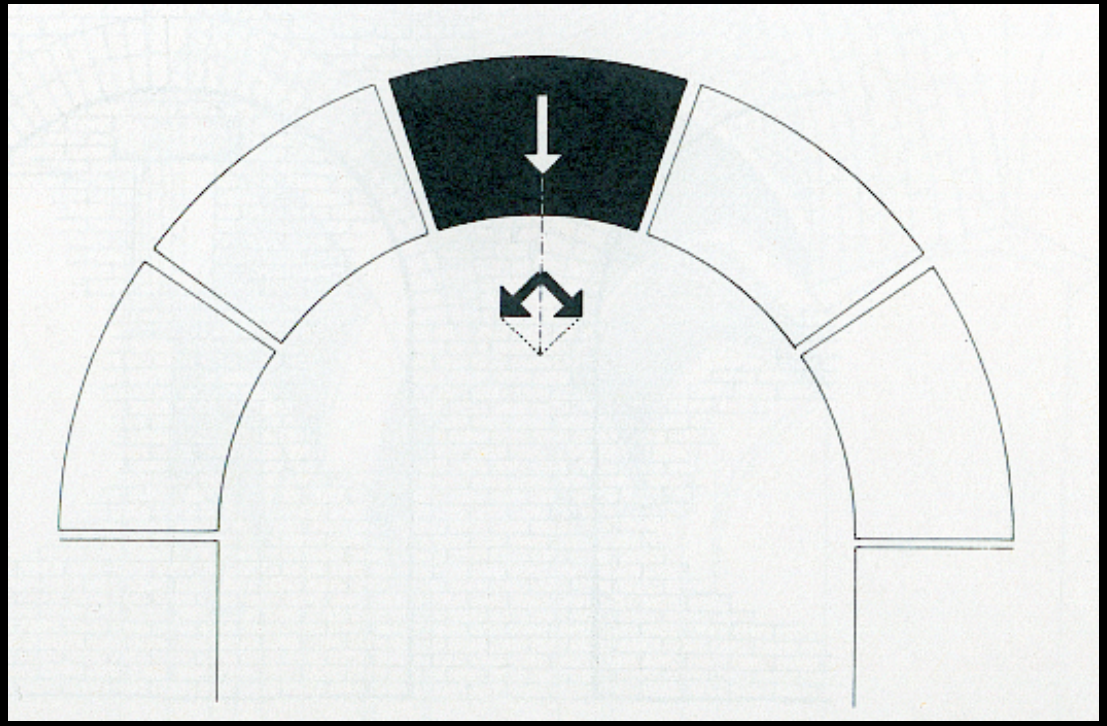


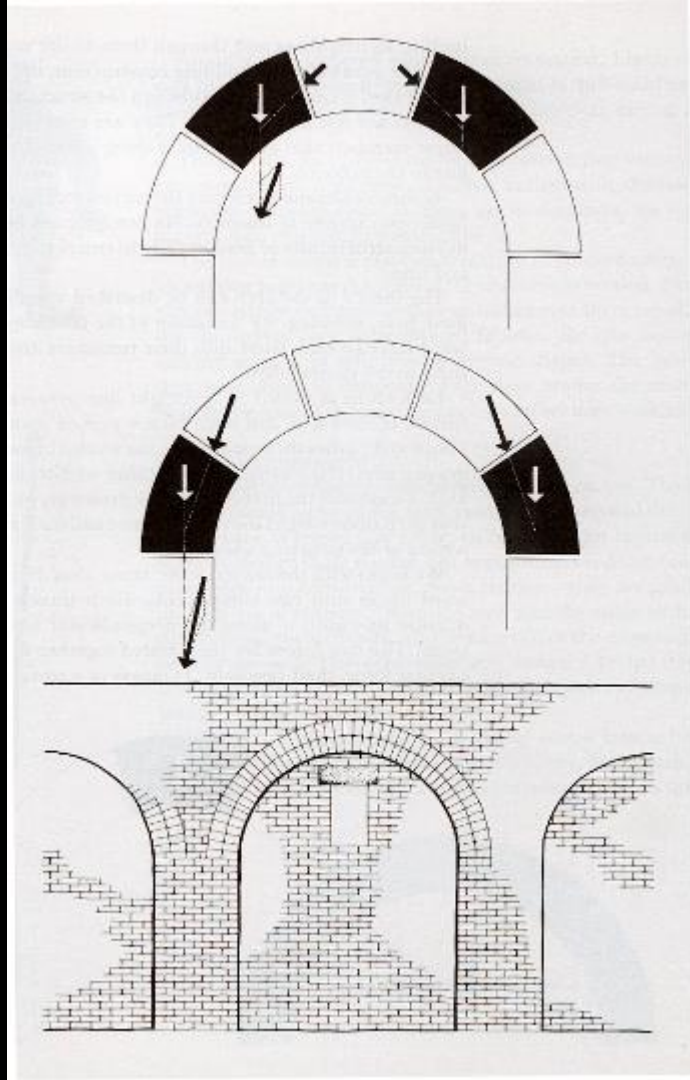
Cable



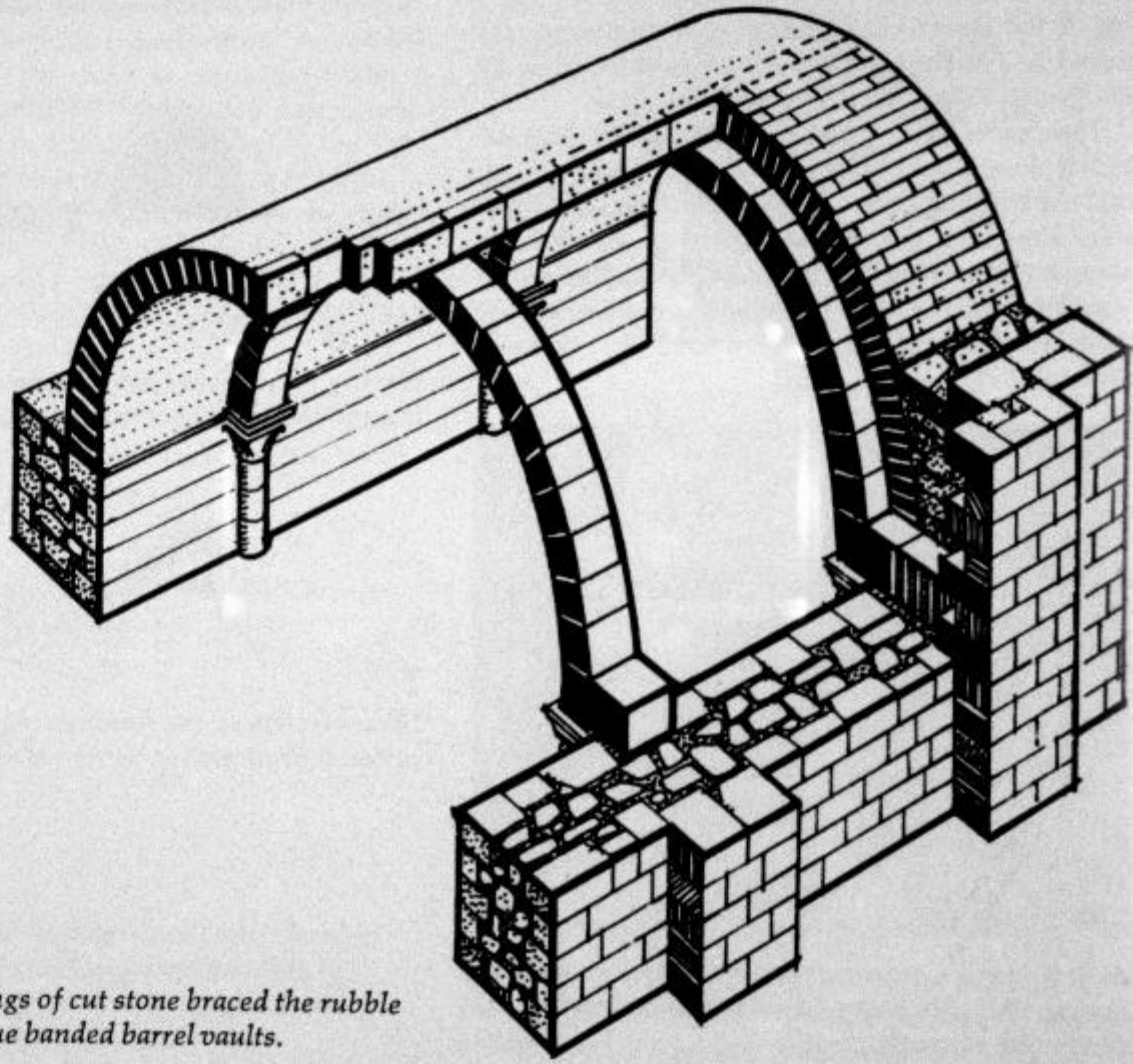
Arch

Using the arch to SPAN

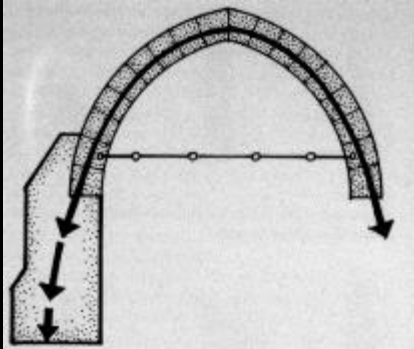




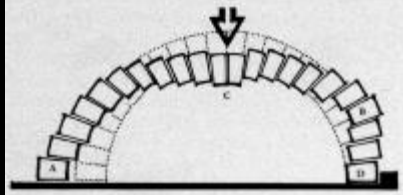
A BARREL VAULT is essentially a row of semi circular arches sitting so tightly in a row as to make a continuous, linear arched space (room)



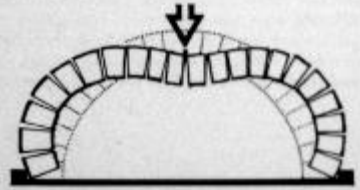
Transverse arch rings of cut stone braced the rubble shell in Romanesque banded barrel vaults.



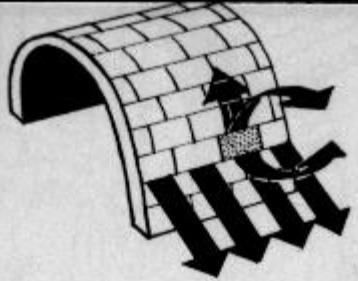
Though the pointed Gothic arch better fits the ideal line of pressure, if too acutely pointed the crown tends to rise while the sides fall inwards. (Similar to saddle failure in pointed corbel vaults)



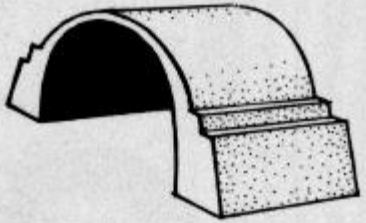
In a semicircular arch where the stones can slide the crown C will fall while the sides B are pressed out above a secure springing D or at the springing itself A.



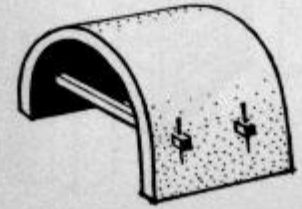
More normal is the rotational deflection of the stones during failure.



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.

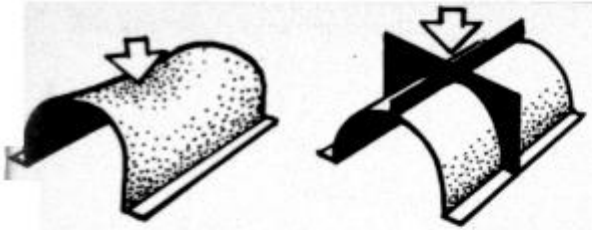


In rare instances, the masons used timber ties to restrain the thrusts of the barrel vault.

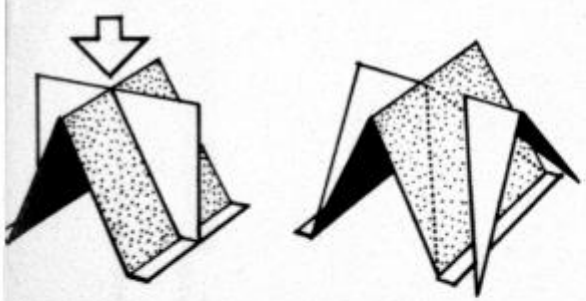
BUTTRESS

A projecting support of stone or brick against a wall

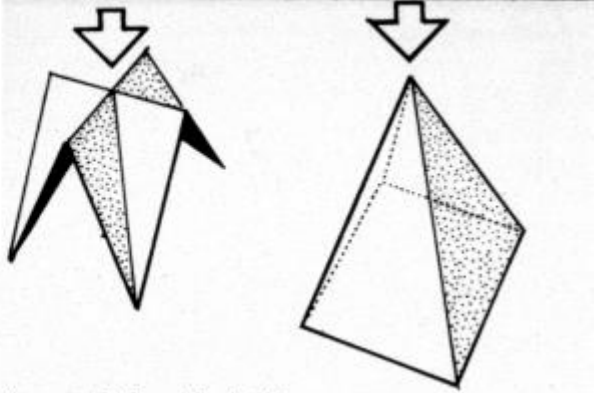
A GROIN VAULT or groined vault (also sometimes known as a double barrel vault or cross vault) is produced by the intersection at right angles of two barrel vaults.
The word "groin" refers to the edge between the intersecting vaults.
The arches may be round (Roman) or pointed (Gothic).



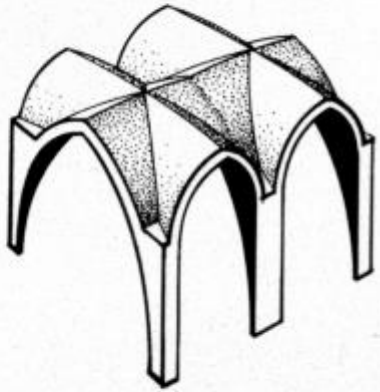
hin cylindrical barrel vaults fail when the crown alls, pushing out the sides. Thin stiffening plates an reduce this flexure.



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

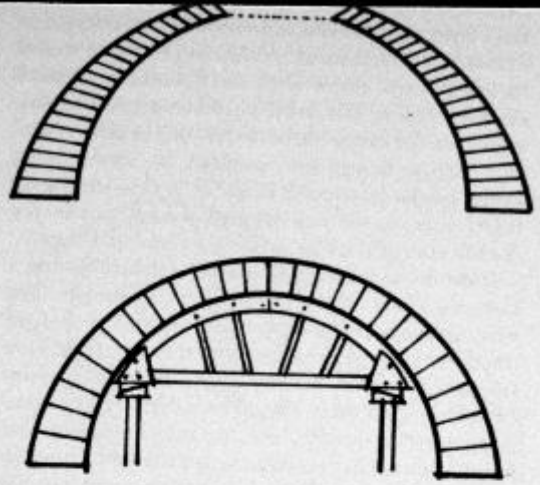


A pyramidal roof is rigid but requires support below the sides. The cross-ridged roof can rest on four isolated supports, channeling loads down the folded groins.

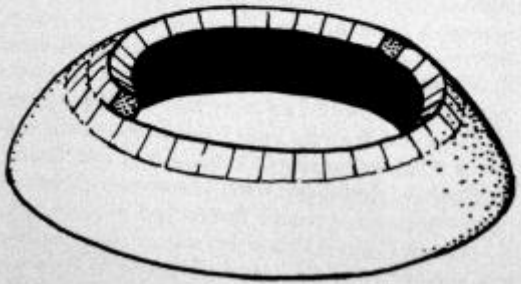


In the pointed Gothic cross vault the panels of aulting were curved to wedge into position

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



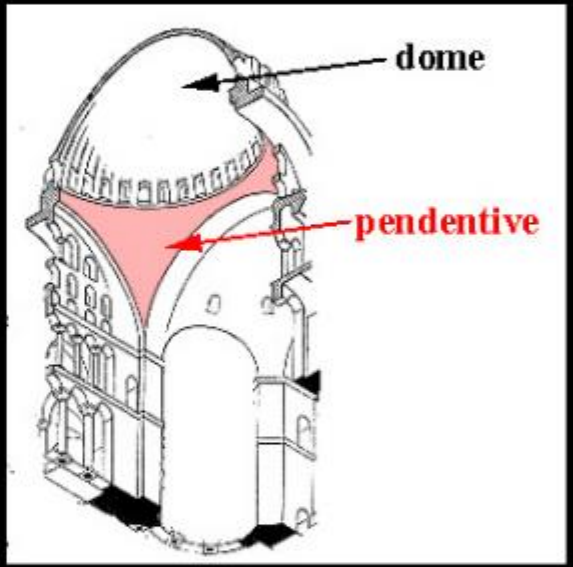
The first domes were developed from beehive corbelled domes by slightly canting the courses. Later domes with steeply pitched radiating joints required centering.

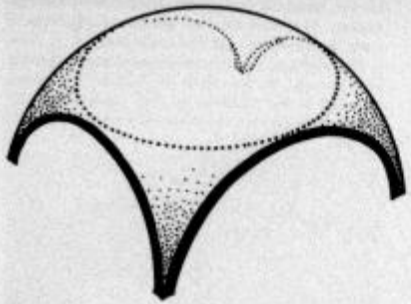


Each ring of masonry in a dome is a structurally stable compression ring.

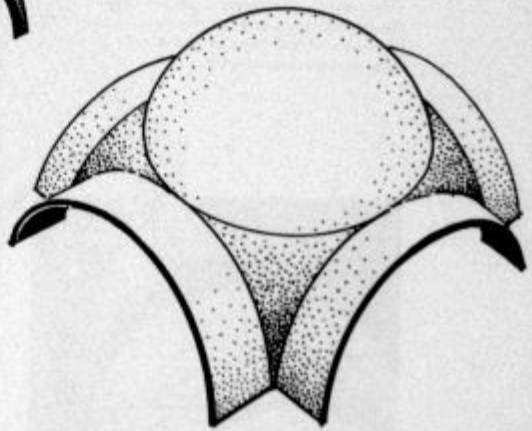
This is what it feels like to be a dome.

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.

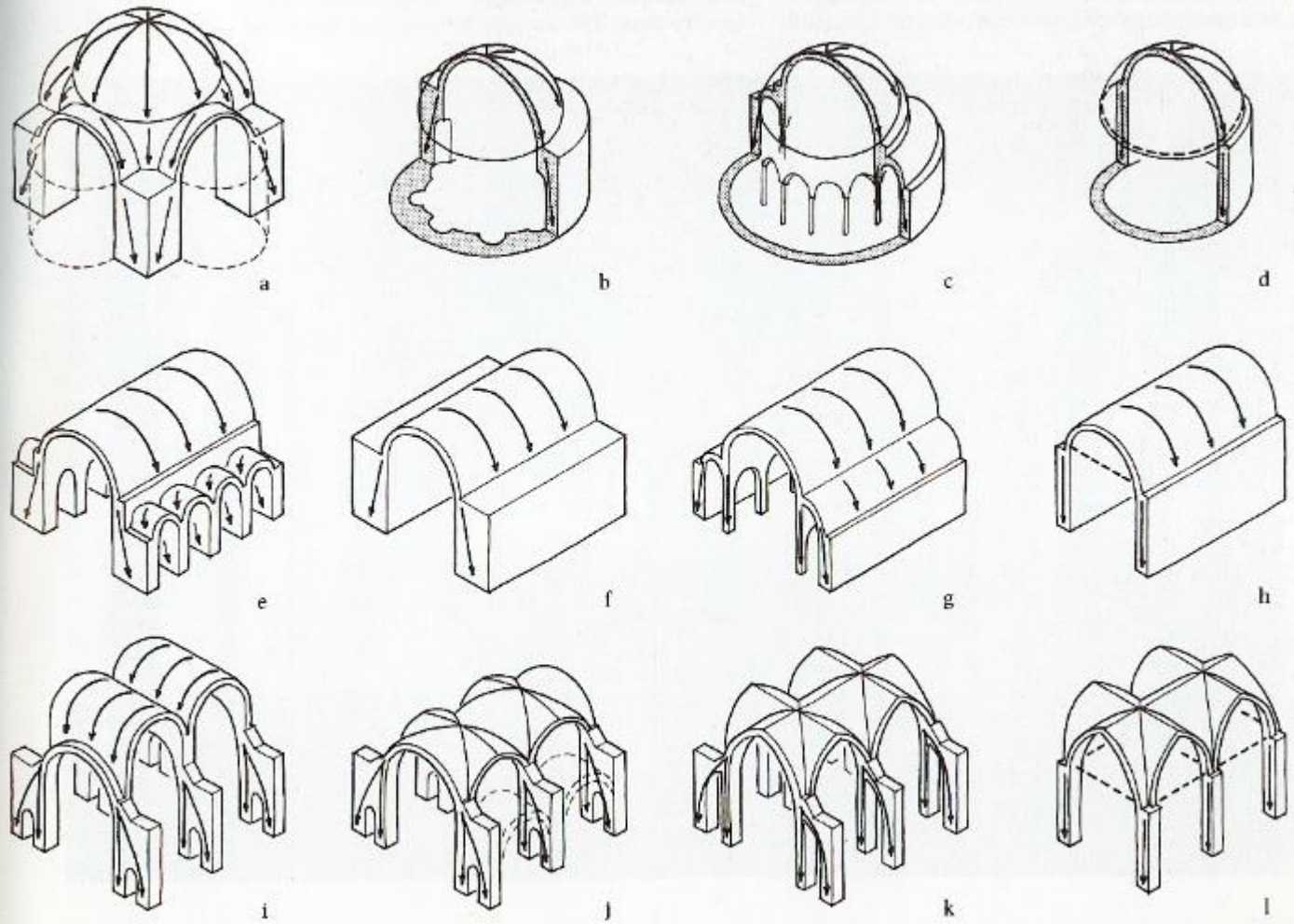




In domes on pendentives the mason could rely on the stiffness of doubly curved surfaces.



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

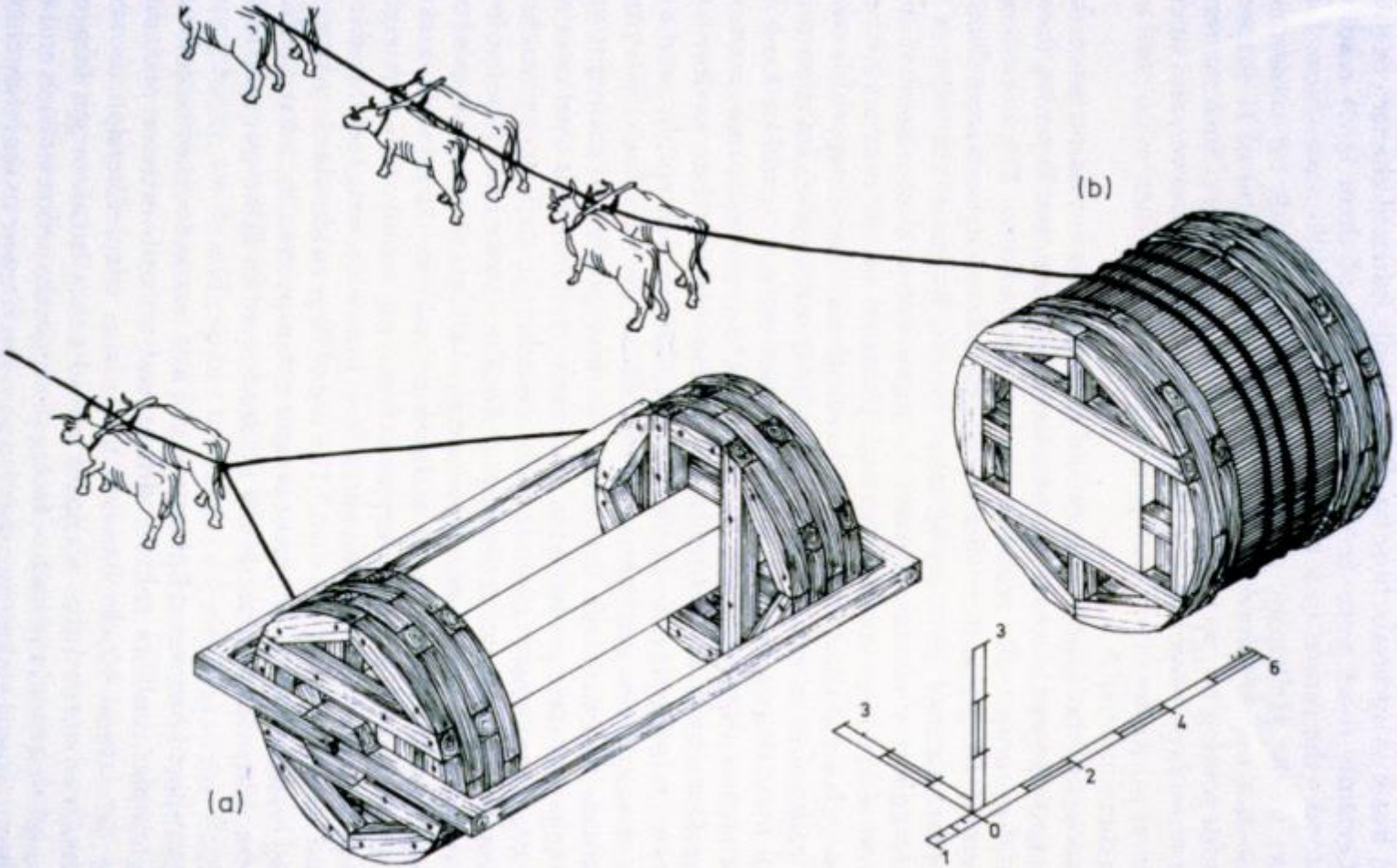

a
b
c
d
e
f
g
h
i
j
k
l

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)

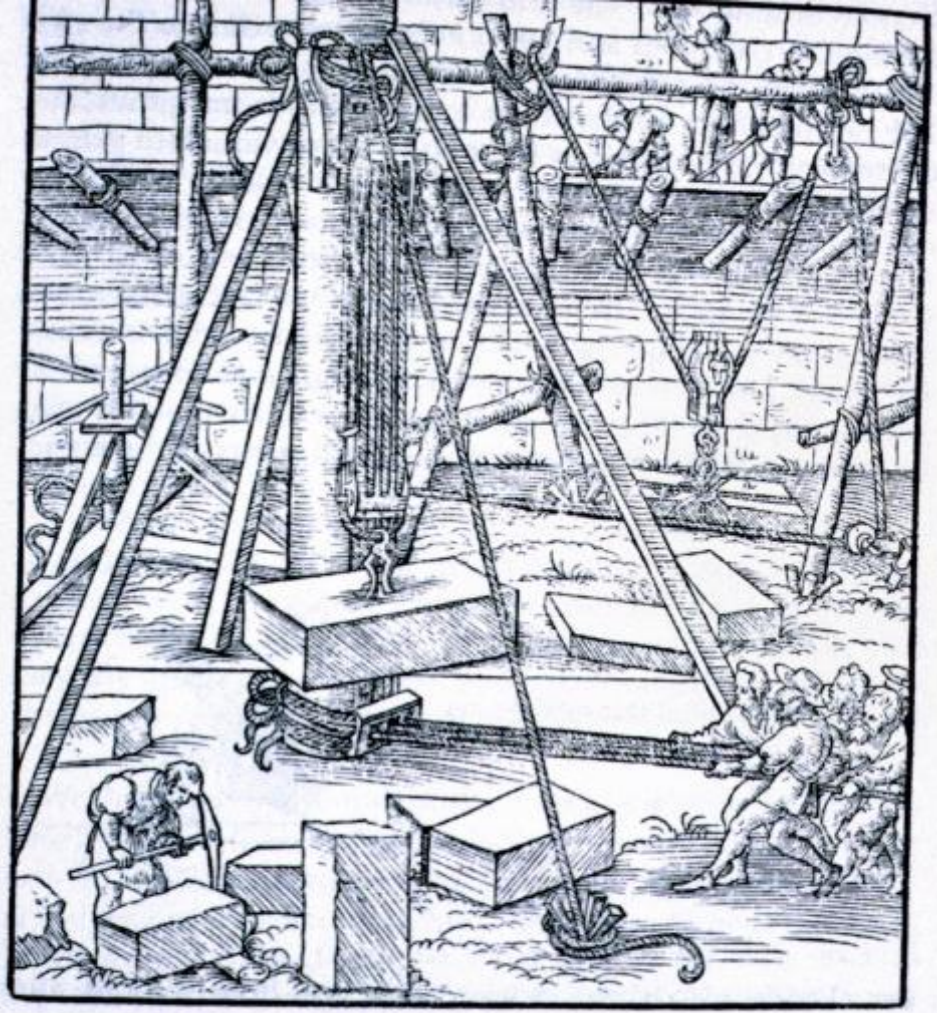
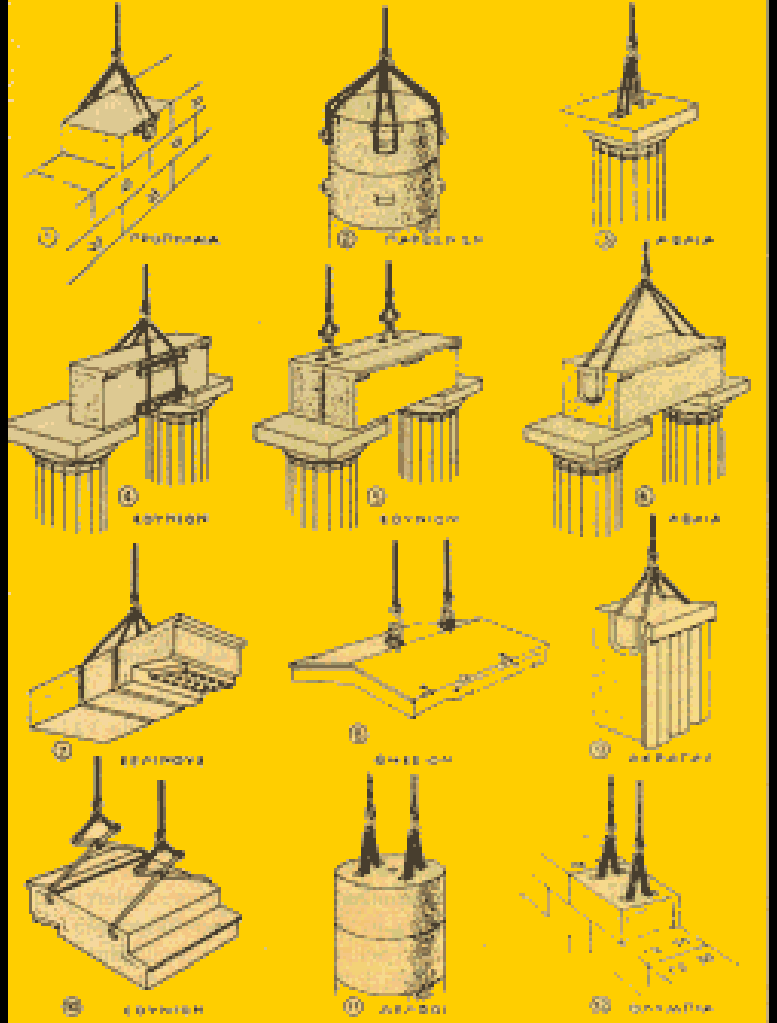


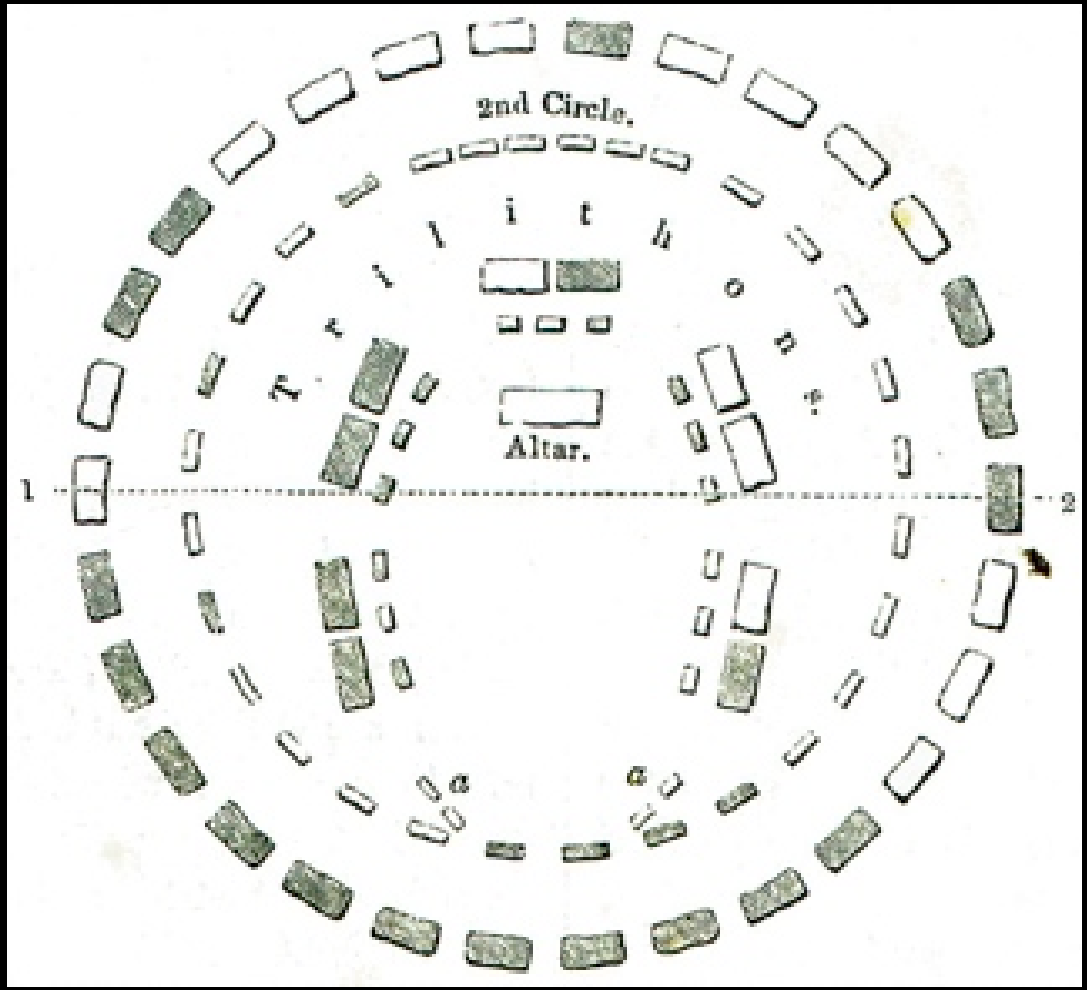
Fig. 139. Levering machinery



TECHNIQUE versus TECHNOLOGY

trial and error versus mathematics and physics

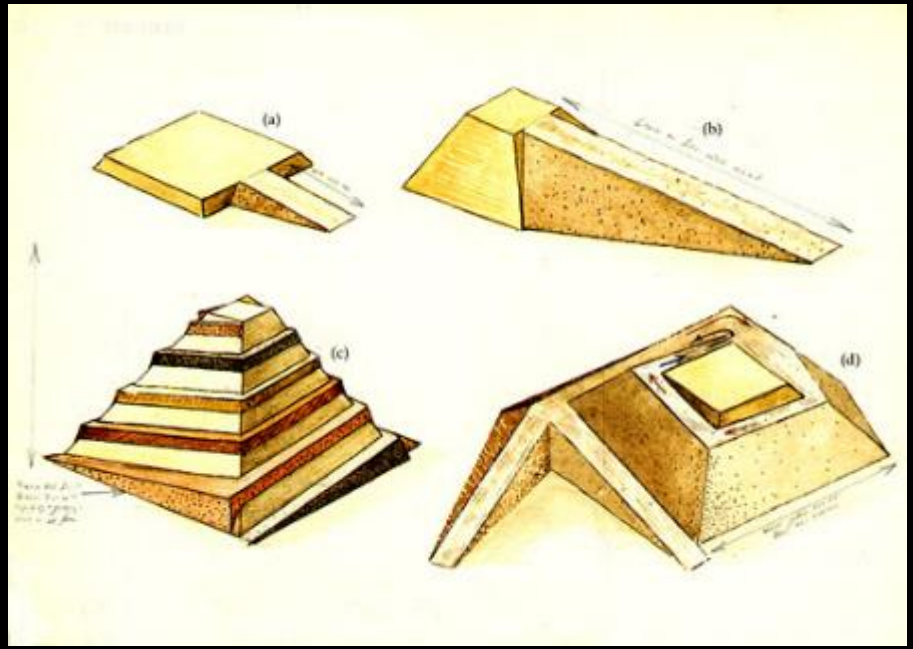

Stonehenge
Wiltshire, England
Circa 3000 BCE
Downloaded from Knowth.com


2nd Circle.
Altar.
1
2

Law Code of Hammurabai
1750 BCE

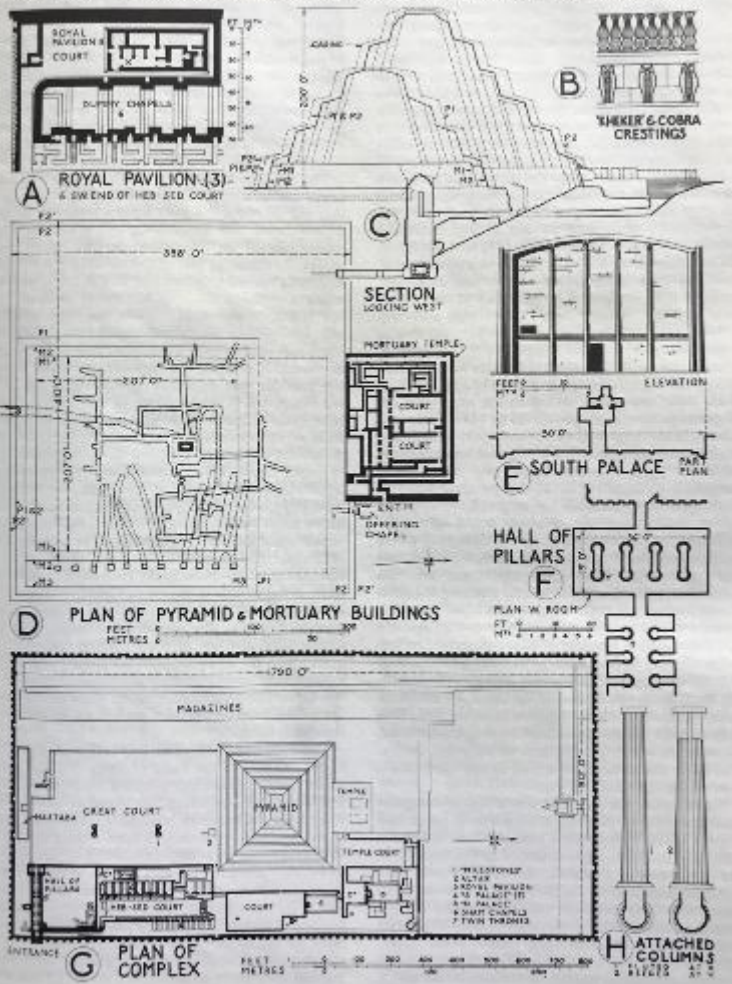
If a builder build a house for a man and do not
make its construction firm,
and the house which he has built collapse
and cause the death of the owner of the house,
that builder shall be put to death.
If it cause the death of a son of the owner of the house,
they shall put to death a son of that builder.

Ancient Stone Techniques


(a)
(b)
(c)
(d)

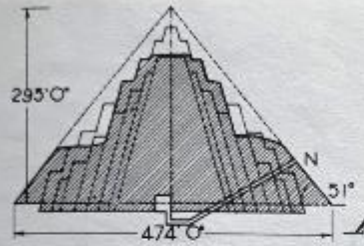
The Stepped Pyramid of Djoser at Saqqara
27th Century BCE

STEP PYRAMID OF ZOSER: SAKKARA

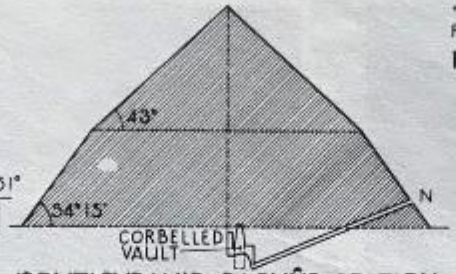


Pyramids at Giza
(Khufu/Cheops, Khafre/Chephren and Menkaure)
2580 BCE

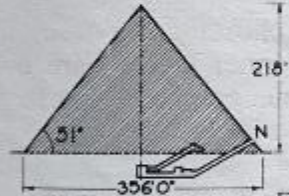
PYRAMIDS AND ATTENDANT BUILDINGS



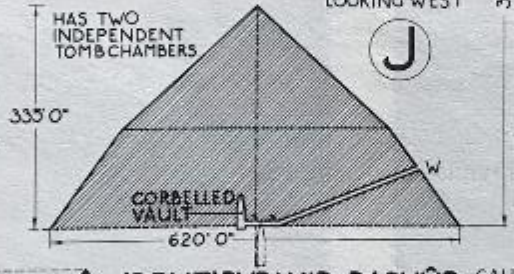
PYRAMID AT ME
H SECTION
LOOKING WEST



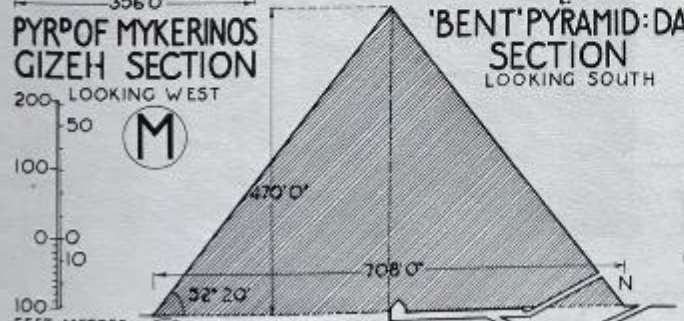
'BENT' PYRAMID: DASHÛR: SECTION
LOOKING WEST
J



PYR^D OF MYKERINOS
GIZEH SECTION
LOOKING WEST
M

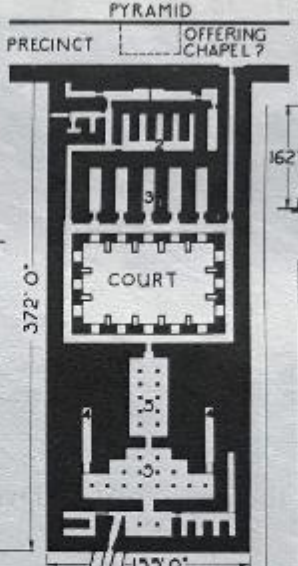


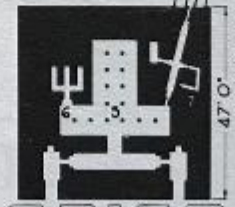
'BENT' PYRAMID: DASHÛR
SECTION
LOOKING SOUTH



K SECTION LOOKING WEST
PYRAMID OF CHEPHREN GIZEH

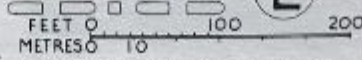
FEET METRES
SCALE FOR
ALL PYRAMID
SECTIONS





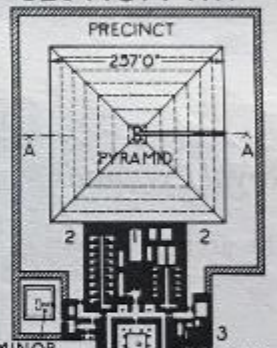
1 SANCTUARY
2 STORES
3 SHRINES
4 SERDABS
5 HALLS
6 2-STOREY CHAMBERS
7 UP TO ROOF

PLANS
L



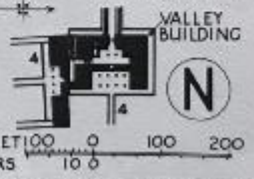
MORTUARY TEMPLE & VALLEY
BUILDING ? CHEPHREN: GIZEH

SECTION 'A A'



1 SANCTUARY
2 STORES
3 UP TO ROOF
4 LANDING

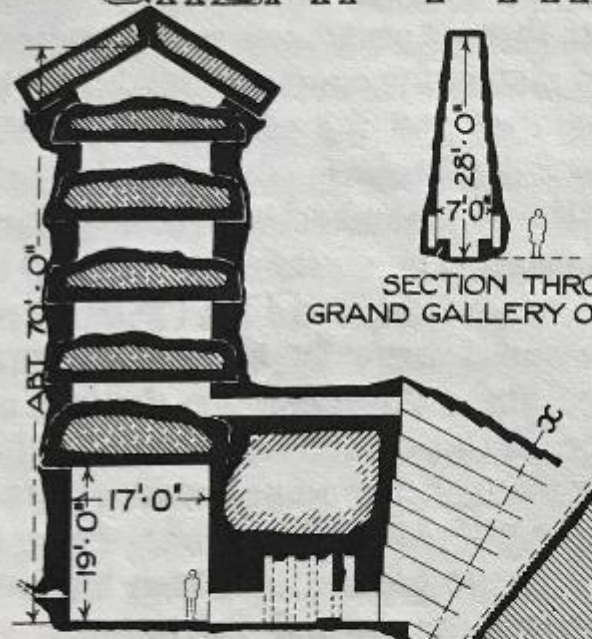
PLAN



N

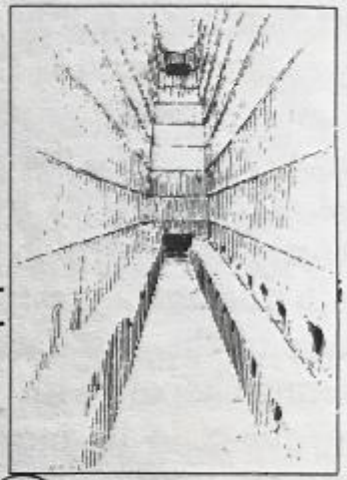
PYRAMID COMPLEX
? SAHURA : ABUSÎR

GREAT PYRAMID OF CHEOPS : GIZEH



SECTION THRO'
GRAND GALLERY ON X-X

C ENTRANCE AT z.



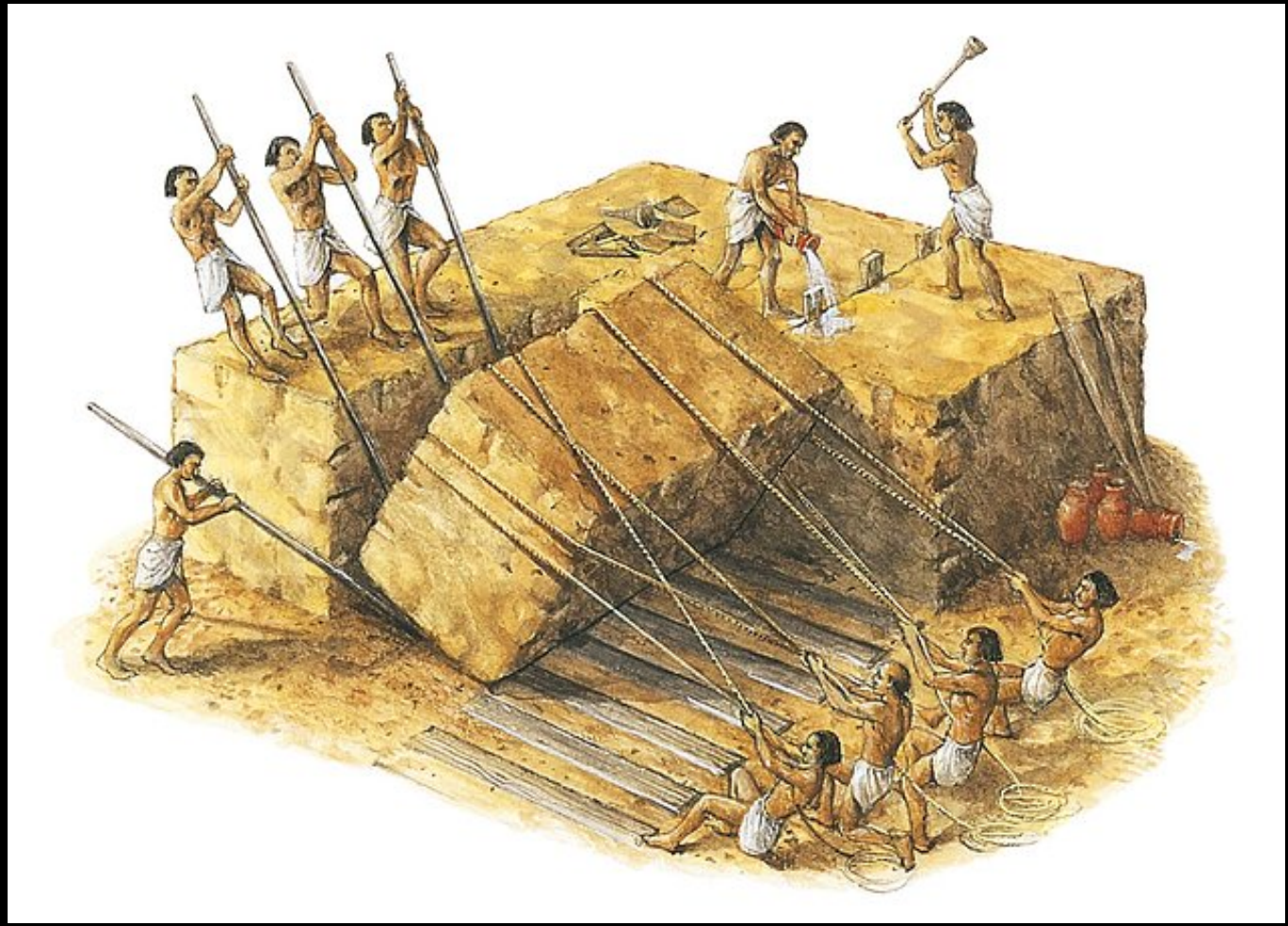
D GRAND GALLERY TO KING'S CHAMBER

A SECTION THRO' KING'S CHAMBER

B SECTION THRO' PYRAMID

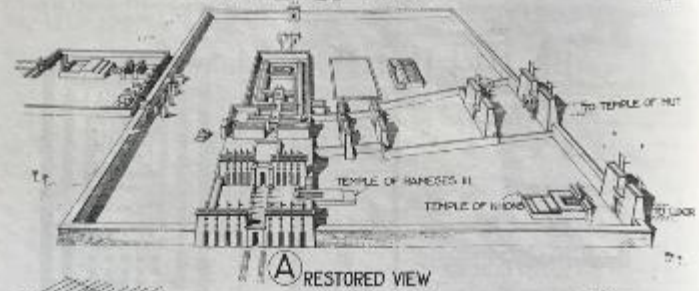
SUBTERRANEAN CHAMBER

E ROCKERS FOR RAISING STONES




Temple at Karnak
Thebes, Egypt
2050 BCE

GREAT TEMPLE OF AMMON: KARNAK



A RESTORED VIEW

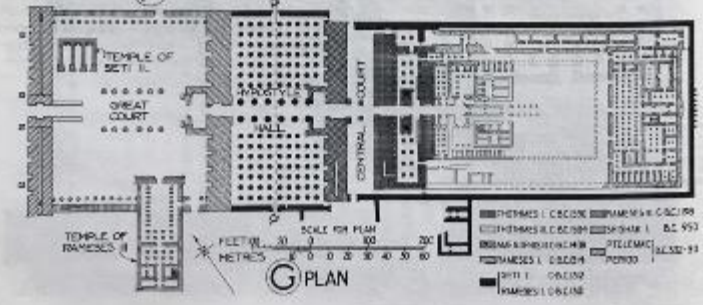
B THE CLEARSTORY
HYPOSTYLE HALL

C ENTRANCE PYLONS (AS EXISTING)

D ROOF APERTURES
LIGHTING INNER HALLS

E AUXILIARY LIGHT-HOLES
HYPOSTYLE HALL

F SECTIONAL VIEW OF HYPOSTYLE HALL ON a.-a.



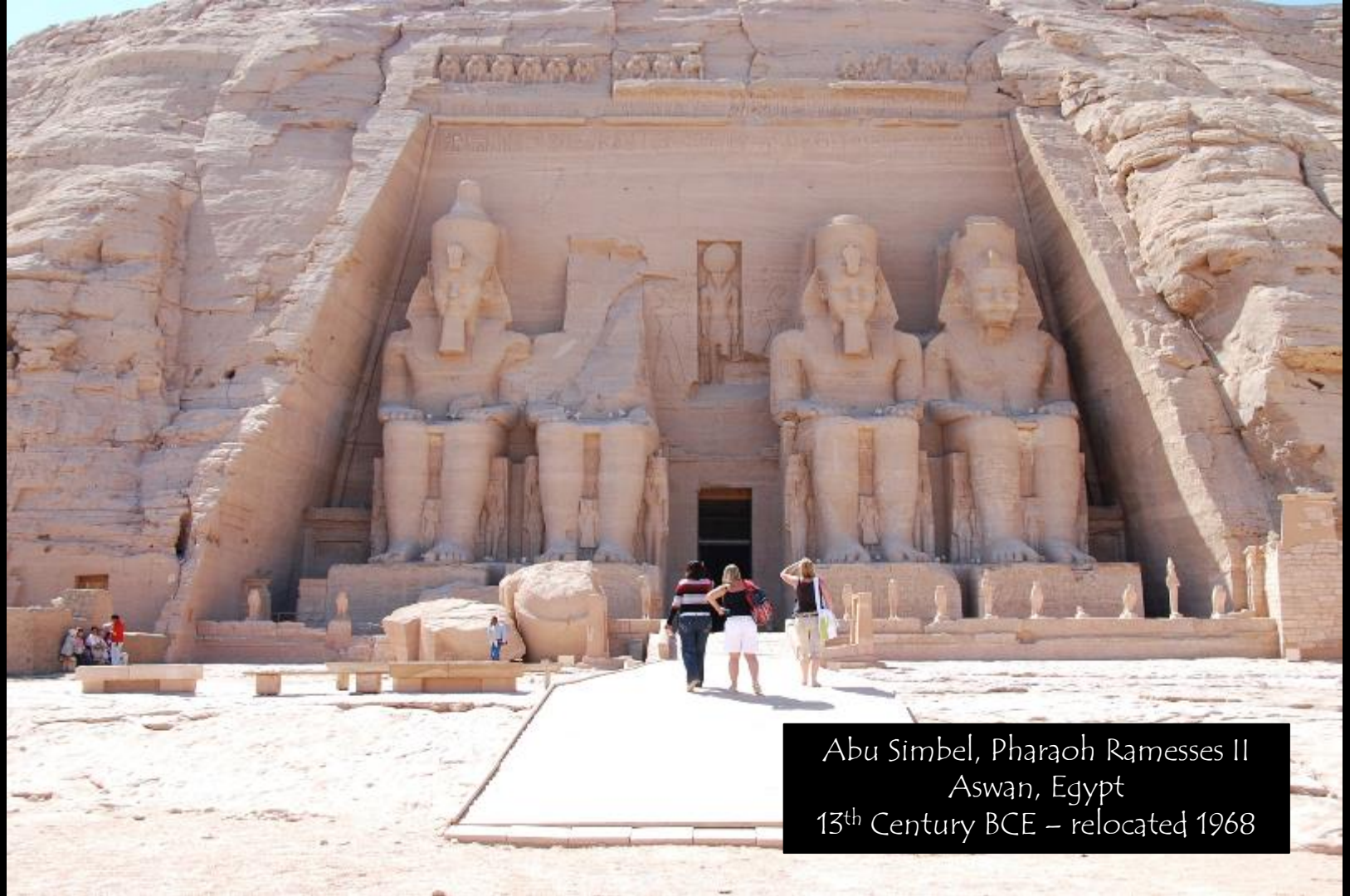
G PLAN

Hypostyle (hall)
Where the roof is supported by a virtual sea of columns

Because stone cannot span very far and no other spanning methods were known at the time

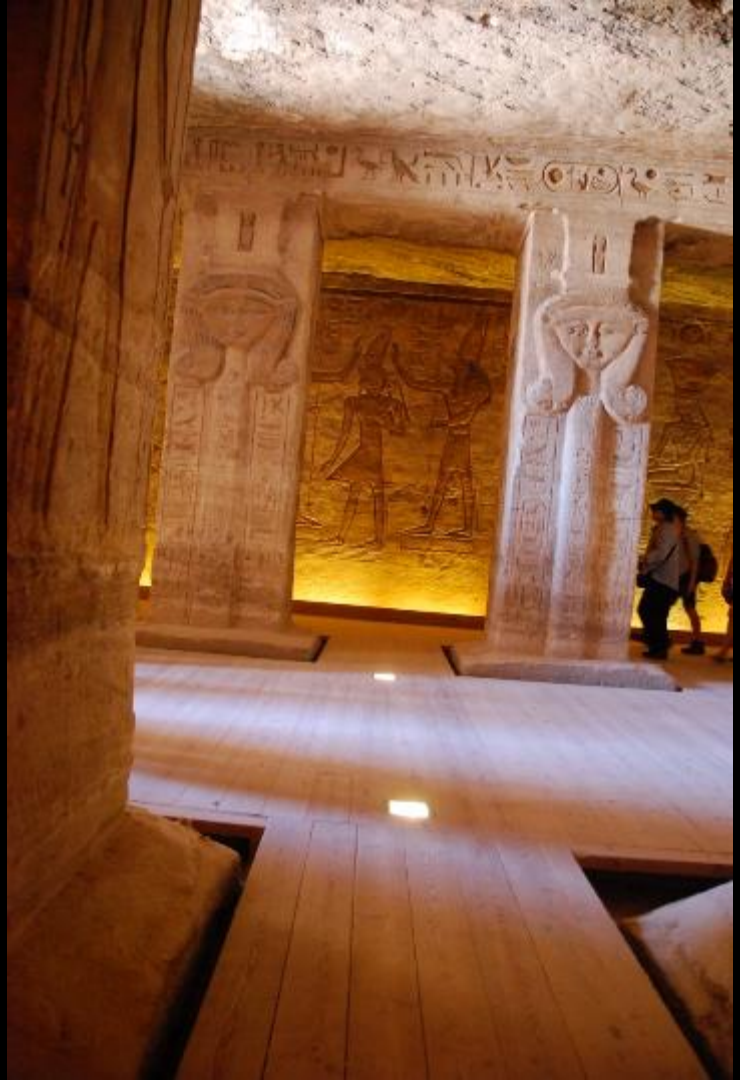

STONE CANNOT SPAN!
IT HAS ZERO TENSILE ABILITY

Mortuary Temple of Hatshepsut
Valley of the Queens, Egypt
1479 BCE



Abu Simbel, Pharaoh Ramesses II
Aswan, Egypt
13th Century BCE – relocated 1968


NO PHOTO INSIDE
THE TEMPLE

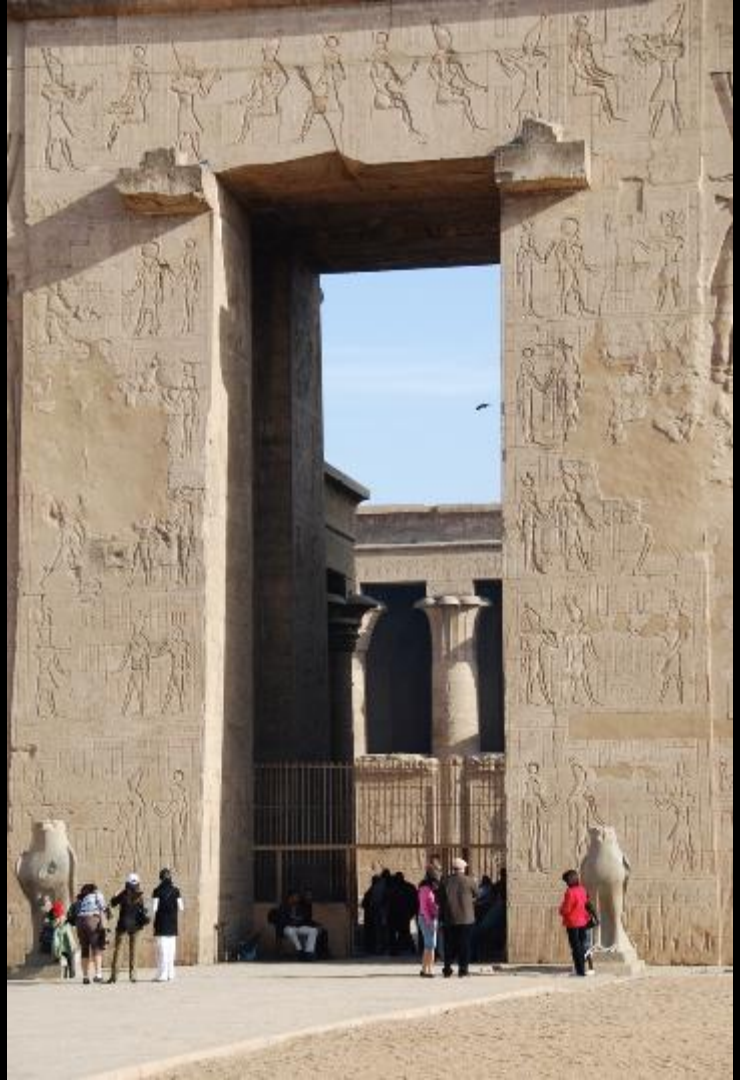


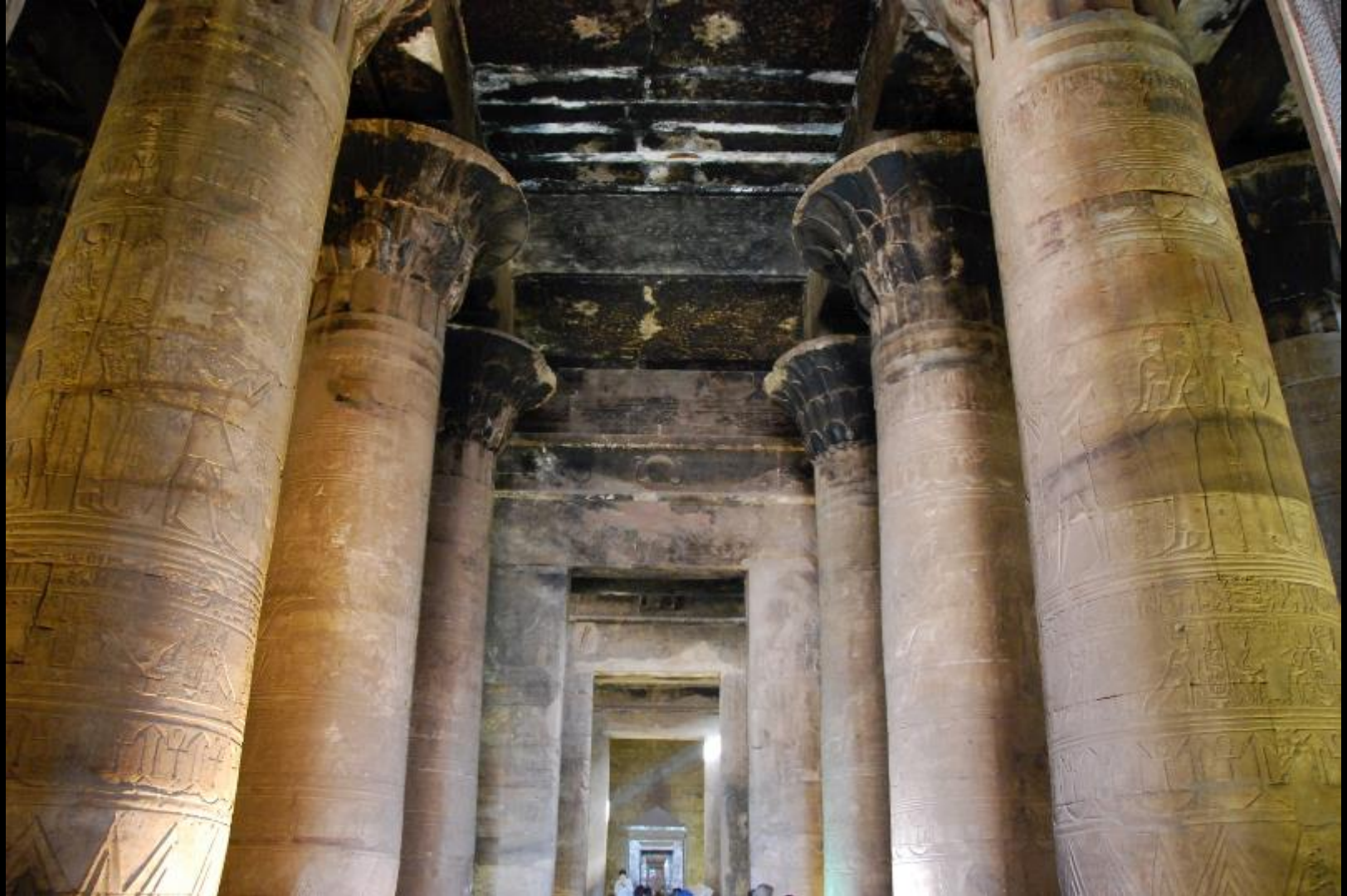
Tomb of Ramesses III
Valley of the Kings, Egypt
1155 BCE

Säulenkapitäle von Philae.

The Temple of Isis at Philae
Aswan, Egypt
380 BCE

The Temple of Horus at Edfu
Ptolemaic Kingdom
237 BCE



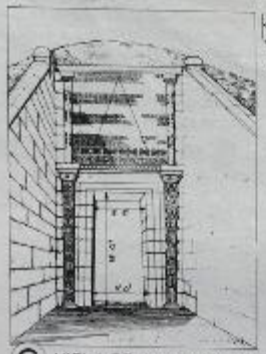



Lion Gate
Bronze Age Citadel
Mycenae, Greece
1250 BCE

TREASURY OF ATREUS: MYCENÆ

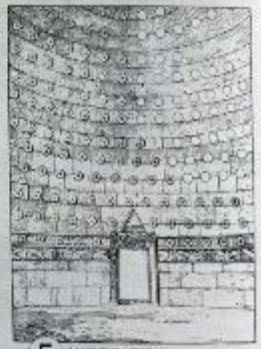
A SECTION

B PLAN



C VIEW OF DROMOS RESTORED

D PORTION OF SHAFT



E INTERIOR RESTORED

F FRAGMENT FROM FAÇADE

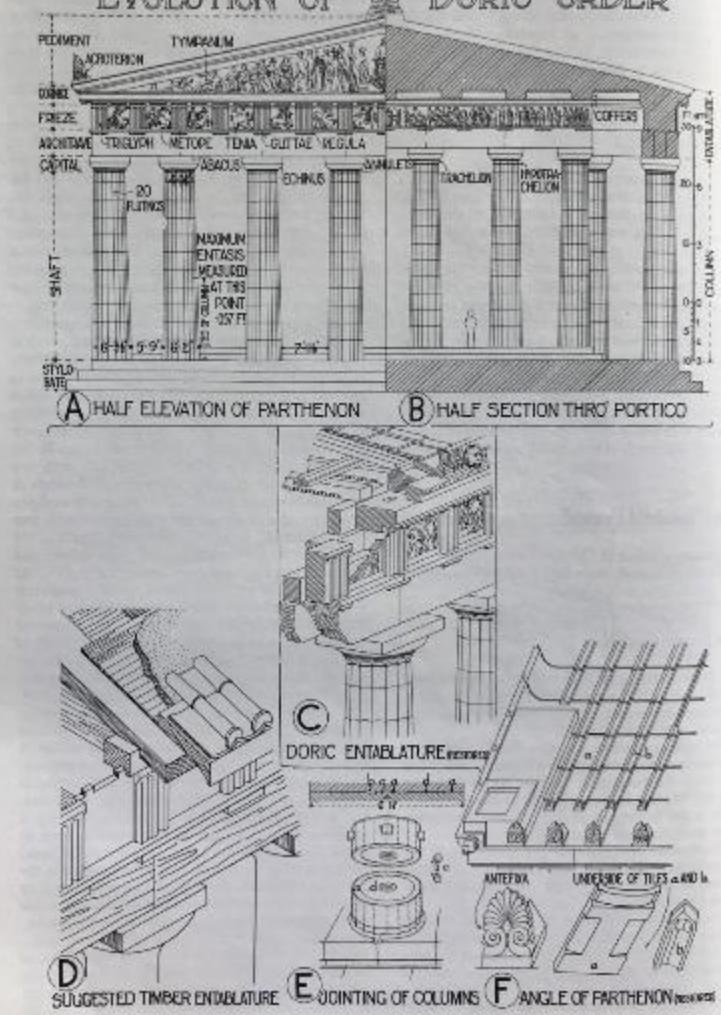
G FRAGMENT FROM FAÇADE

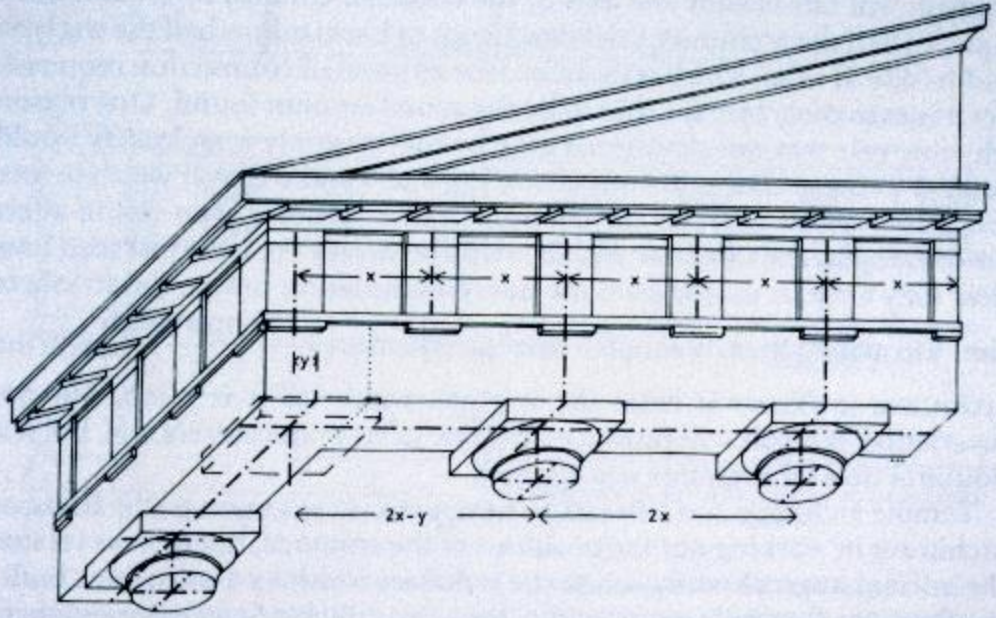
H SCULPTURE: GATE OF LIONS: MYCENÆ


Great Wall of China
From 7th Century BCE

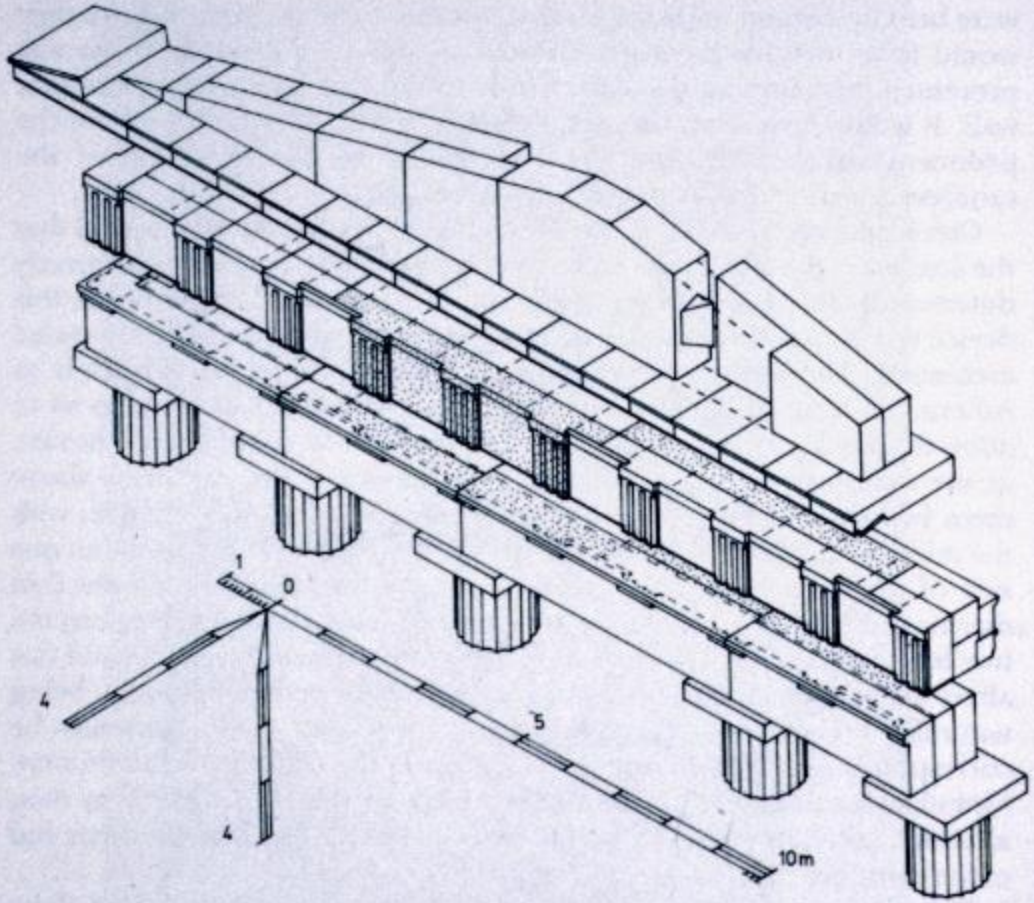
Four main CLASSICAL column styles

Doric
Ionic
Corinthian
Composite

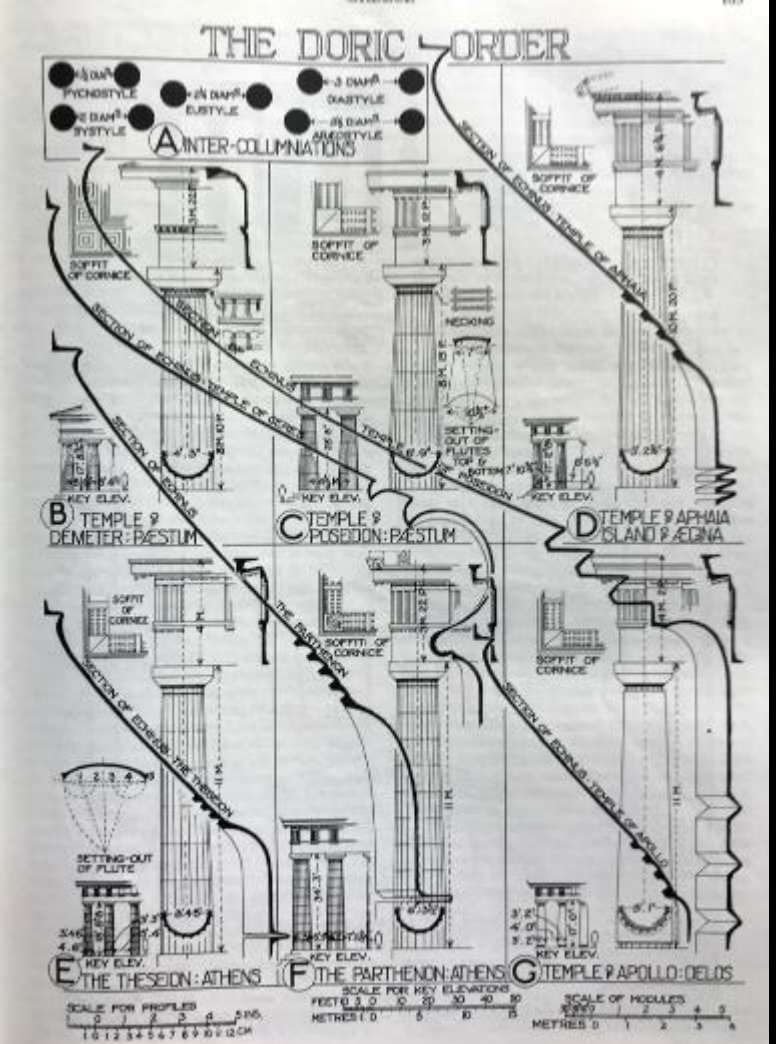




18 Angle contraction in the Doric order: elevation with oblique projection

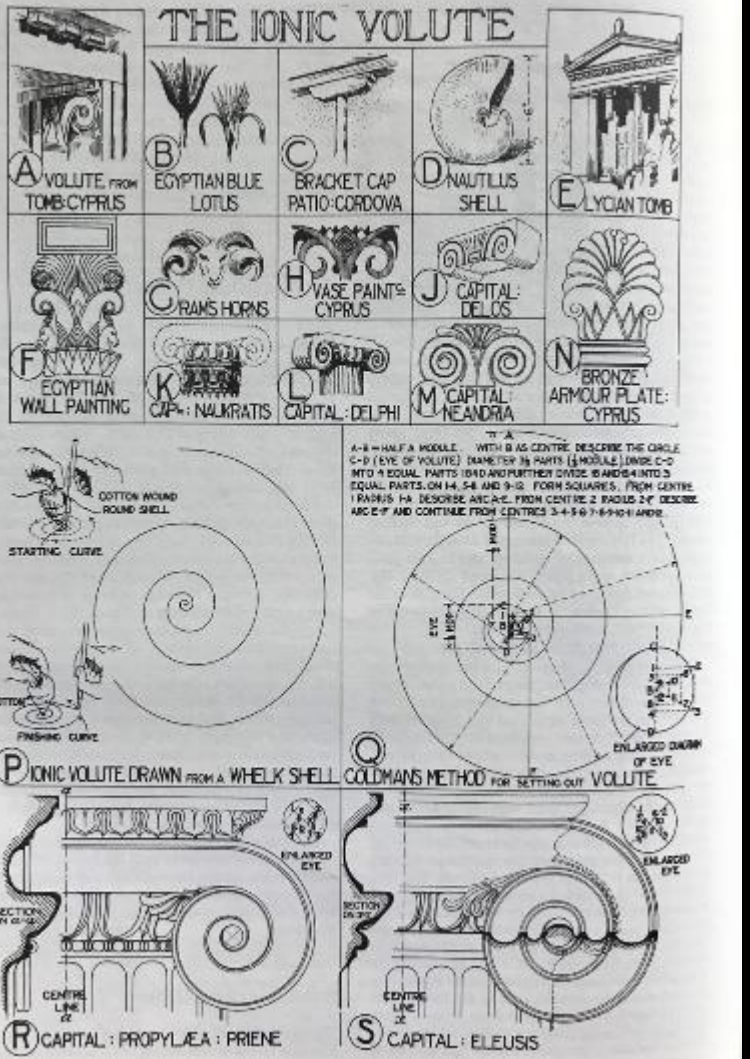


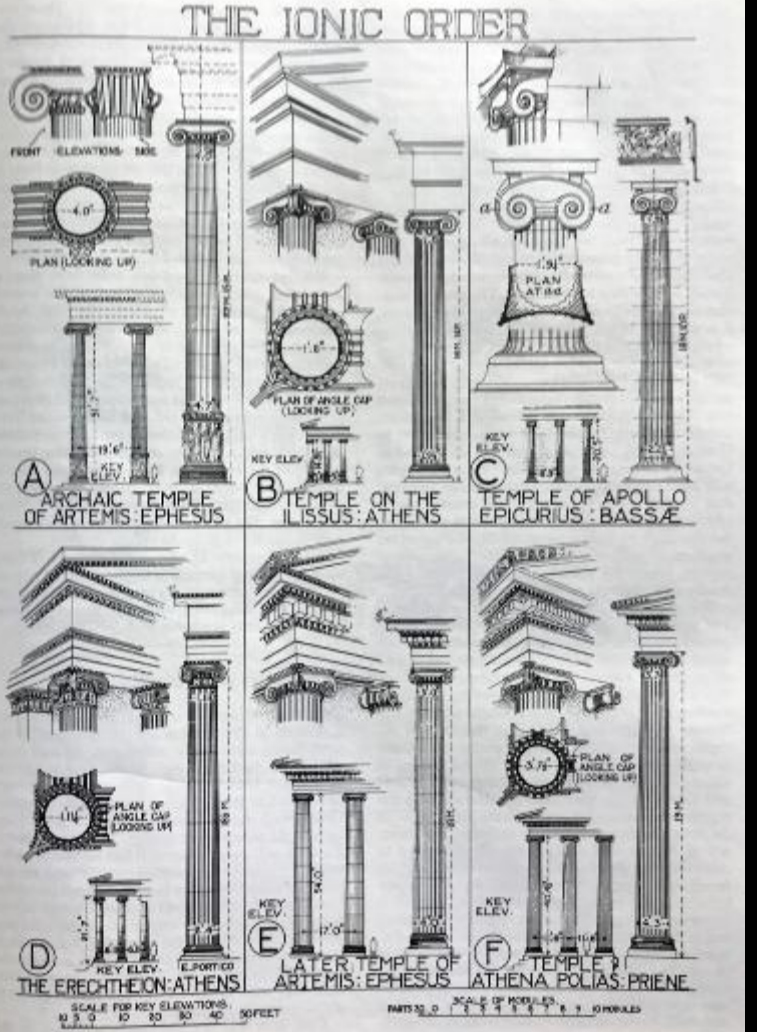
67 Propylaia at Athens, east façade (*c.* 437–432 B.C.): exploded isometric view showing cantilevered frieze beams


THE DORIC ORDER
PYCNOSTYLE
EUSTYLE
DIASTYLE
SYSTYLE
ARAEOSTYLE
A INTER-COLUMNIATIONS
SOFFIT OF CORNICE
NECKING
SETTING-OUT OF FLUTES TOP & BOTTOM
KEY ELEV.
B TEMPLE OF DEMETER: PAESTUM
C TEMPLE OF POSEIDON: PAESTUM
D TEMPLE OF APHAIA ISLAND OF ÆGINA
SECTION OF ECHINUS, TEMPLE OF APHAIA
SECTION OF ECHINUS, TEMPLE OF CERES
SECTION OF ECHINUS, TEMPLE OF POSEIDON
SECTION OF ECHINUS, THE PARTHENON
SECTION OF ECHINUS, TEMPLE OF APOLLO
SETTING-OUT OF FLUTE
E THE THESEION: ATHENS
F THE PARTHENON: ATHENS
G TEMPLE OF APOLLO: DELOS
SCALE FOR PROFILES
SCALE FOR KEY ELEVATIONS
FEET
METRES
SCALE OF MODULES
METRES


ΔΩΡΙΚΟΝ
DORIC

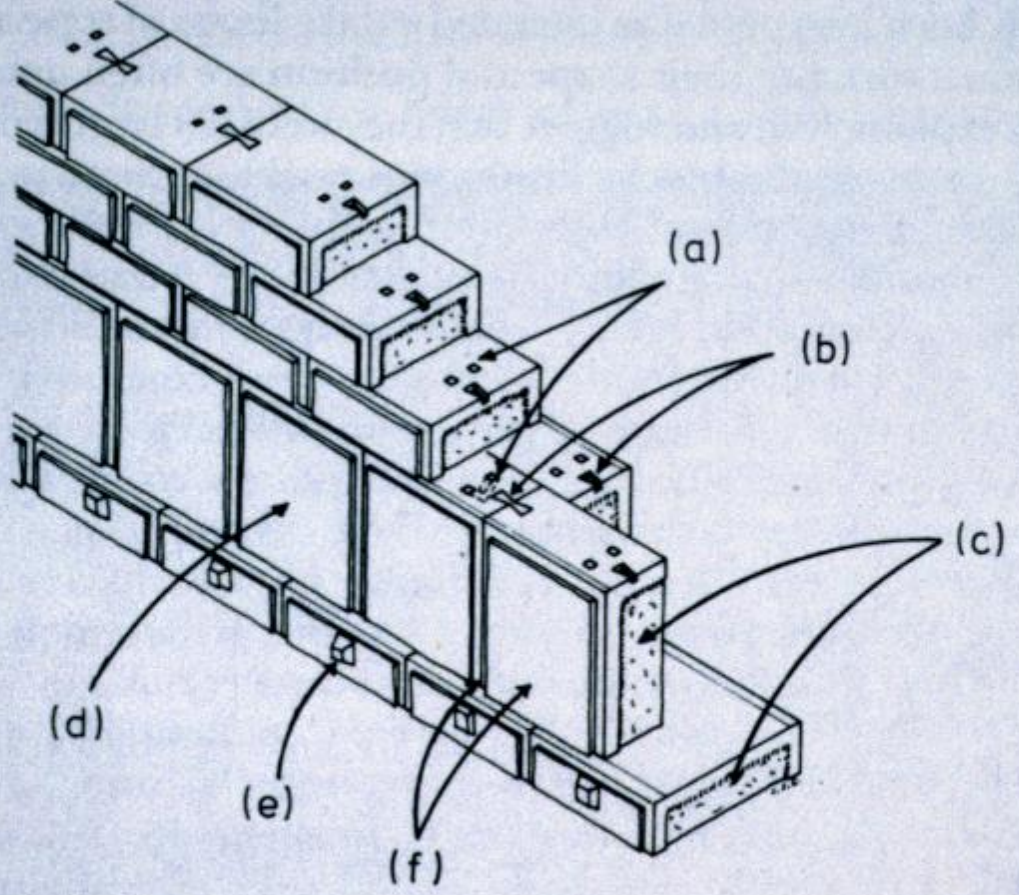

Temple of Apollo
Ancient Corinth,
Greece
550 BCE


THE IONIC VOLUTE
A VOLUTE, FROM TOMB: CYPRUS
B EGYPTIAN BLUE LOTUS
C BRACKET CAP PATIO: CORDOVA
D NAUTILUS SHELL
E LYCIAN TOMB
F EGYPTIAN WALL PAINTING
G RAM'S HORNS
H VASE PAINTG CYPRUS
J CAPITAL: DELOS
K CAP: NAUKRATIS
L CAPITAL: DELPHI
M CAPITAL: NEANDRIA
N BRONZE ARMOUR PLATE: CYPRUS
COTTON WOUND ROUND SHELL
STARTING CURVE
COTTON
FINISHING CURVE
A-B = HALF A MODULE. WITH B AS CENTRE DESCRIBE THE CIRCLE C-D (EYE OF VOLUTE) DIAMETER ⅓ PARTS (¼ MODULE) DIVIDE C-D INTO 4 EQUAL PARTS (B-D) AND FURTHER DIVIDE IS AND B-4 INTO 3 EQUAL PARTS. ON 1-4, 5-8 AND 9-12 FORM SQUARES. FROM CENTRE 1 RADIUS 1-A DESCRIBE ARC A-E. FROM CENTRE 2 RADIUS 2-E DESCRIBE ARC E-F AND CONTINUE FROM CENTRES 3-4-5-6-7-8-9-10-11 AND 12.
EYE
ENLARGED DIAGRAM OF EYE
P IONIC VOLUTE DRAWN FROM A WHELK SHELL
Q COLDMANS METHOD FOR SETTING OUT VOLUTE
ENLARGED EYE
SECTION ON AT
CENTRE LINE OF
R CAPITAL: PROPYLÆA: PRIENE
S CAPITAL: ELEUSIS

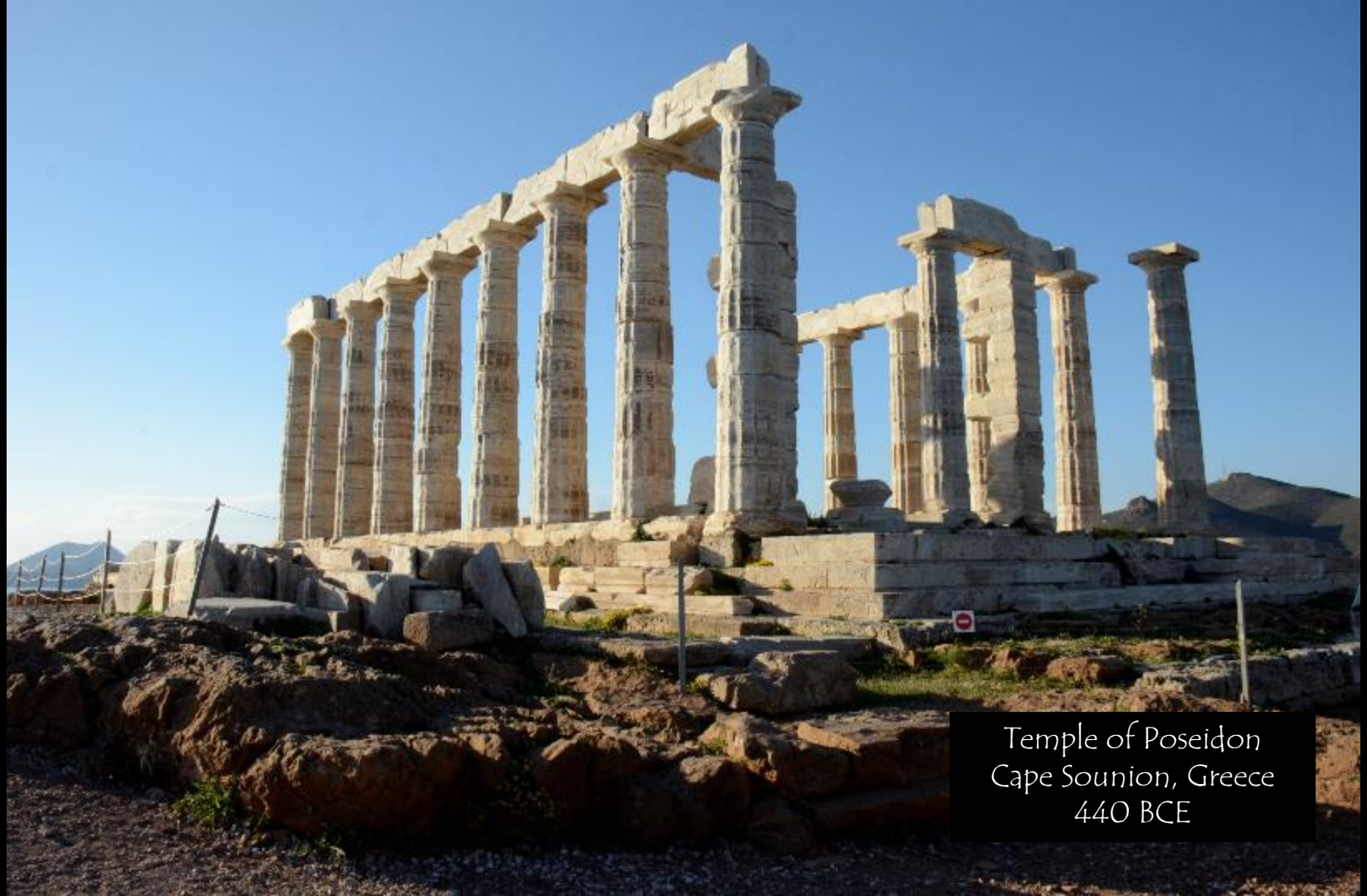

THE IONIC ORDER
FRONT ELEVATIONS SIDE
PLAN (LOOKING UP)
KEY ELEV.
A ARCHAIC TEMPLE OF ARTEMIS: EPHESUS
PLAN OF ANGLE CAP (LOOKING UP)
B TEMPLE ON THE ILISSUS: ATHENS
PLAN AT a-a
C TEMPLE OF APOLLO EPICURIUS: BASSÆ
D THE ERECHTHEION: ATHENS
E.PORT.CO
E LATER TEMPLE OF ARTEMIS: EPHESUS
F TEMPLE OF ATHENA POLIAS: PRIENE
SCALE FOR KEY ELEVATIONS
SCALE OF MODULES


ACANTHUS COLUMN

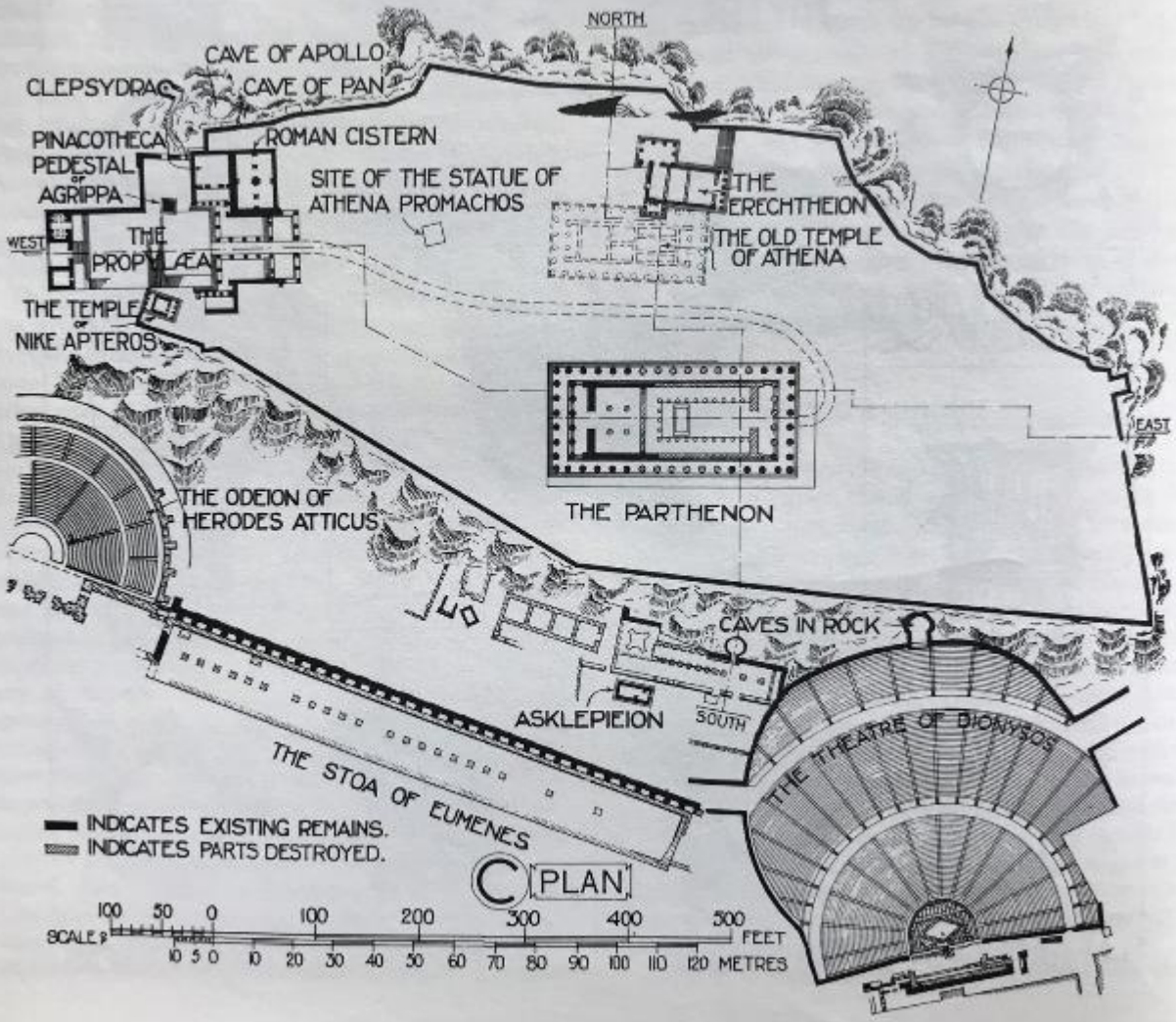

ΚΙΟΝΟΚΡΑΝΟΝ
ΜΕΤΑ ΧΙΜΑΙΡΩΝ
CHIMAERA CAPITAL



12 Features of early Greek monumental masonry: (a) U-shaped hole; (b) dove-tail clamp; (c) band anathyrosis; (d) orthostate; (e) handling boss; (f) preliminary dressing


Temple of Poseidon
Cape Sounion, Greece
440 BCE


Acropolis
Athens, Greece
Circa 500 BCE


NORTH
CAVE OF APOLLO
CLEPSYDRA
CAVE OF PAN
PINACOTHECA
ROMAN CISTERN
PEDESTAL OF AGRIPPA
SITE OF THE STATUE OF ATHENA PROMACHOS
THE ERECHTHEION
THE OLD TEMPLE OF ATHENA
WEST
THE PROPYLÆA
THE TEMPLE OF NIKE APTEROS
EAST
THE ODEION OF HERODES ATTICUS
THE PARTHENON
CAVES IN ROCK
ASKLEPIEION
SOUTH
THE THEATRE OF DIONYSOS
THE STOA OF EUMENES
INDICATES EXISTING REMAINS.
INDICATES PARTS DESTROYED.
C PLAN
SCALE
100 50 0 100 200 300 400 500 FEET
10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 METRES


The Parthenon
Acropolis
Athens, Greece
Circa 500 BCE

THE PARTHENON: ATHENS

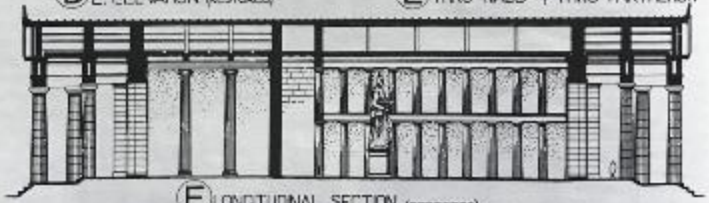
A SECTIONAL VIEW E. END

B E. FACADE (RESTORED)

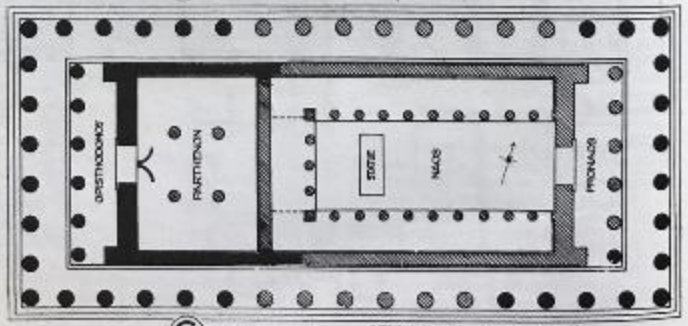
C N.W. ANGLE (RESTORED)

D E. ELEVATION (RESTORED)

E HALF TRANSVERSE SECTNS. THRO' NAOS + THRO' PARTHENON



F LONGITUDINAL SECTION (RESTORED)

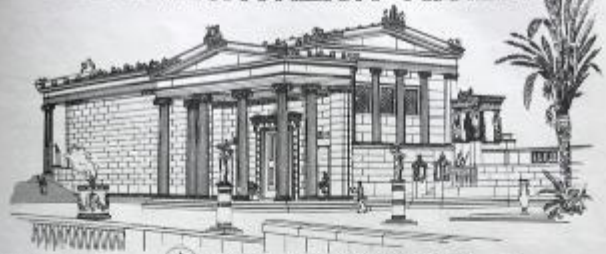


G PLAN (RESTORED)

FT-0 10 20 30 40 50 60
METRES 0 5 10 15


Erectheum
Acropolis
Athens, Greece
Circa 500 BCE

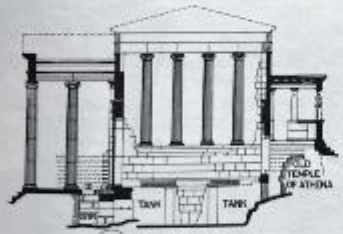
THE ERECHTHEION : ATHENS



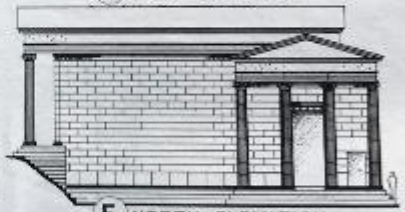
A VIEW FROM NORTH WEST

B EAST ELEVATION

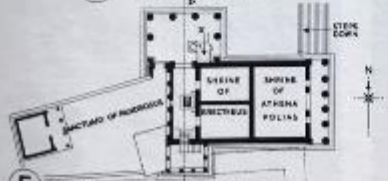
C WEST ELEVATION



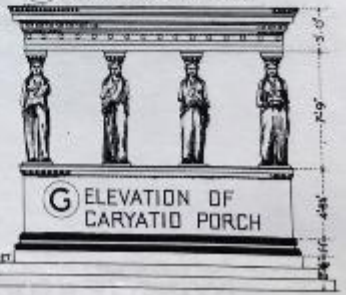
D SECTION A-A



E NORTH ELEVATION



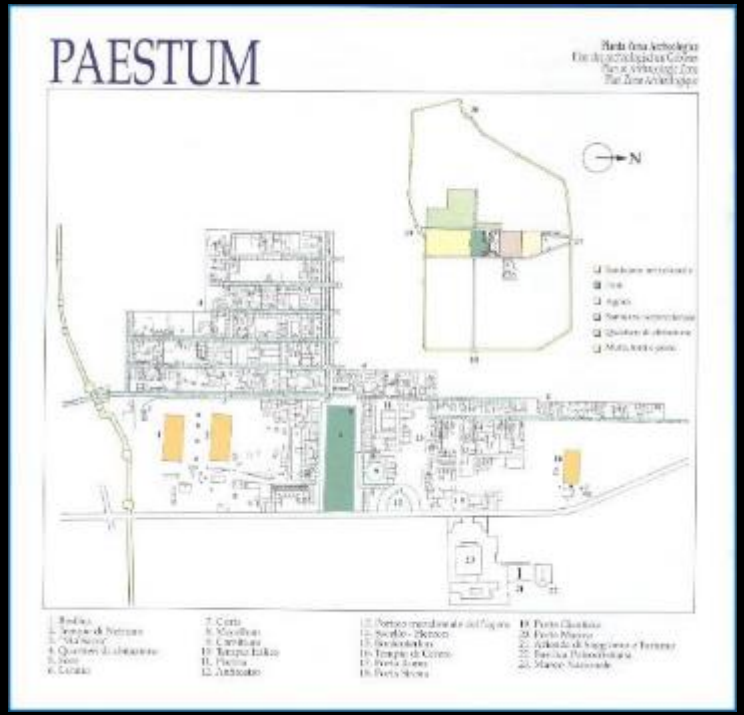
F PLAN

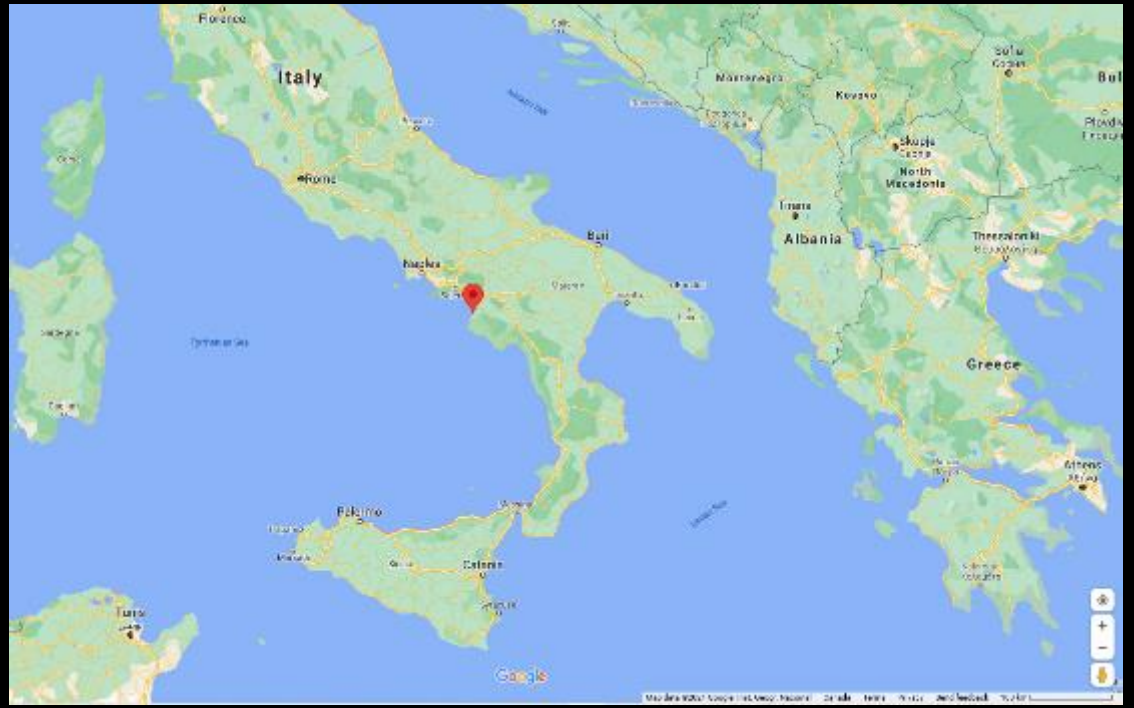


G ELEVATION OF CARYATID PORCH

SCALE FOR ELEVATIONS & SECTIONS

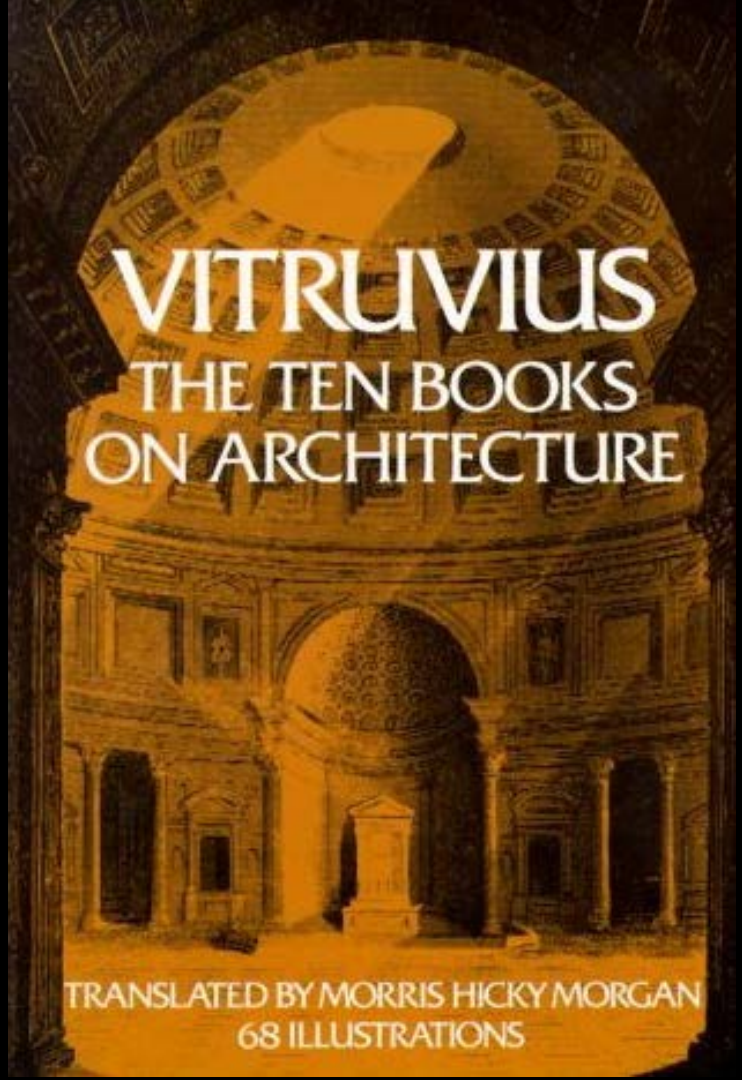
SCALE FOR PLAN


PAESTUM
N


Italy
Albania
Greece
Google

First Temple of Hera
Paestum, Italy
550 BCE

Second Temple of Hera
Paestum, Italy
450 BCE



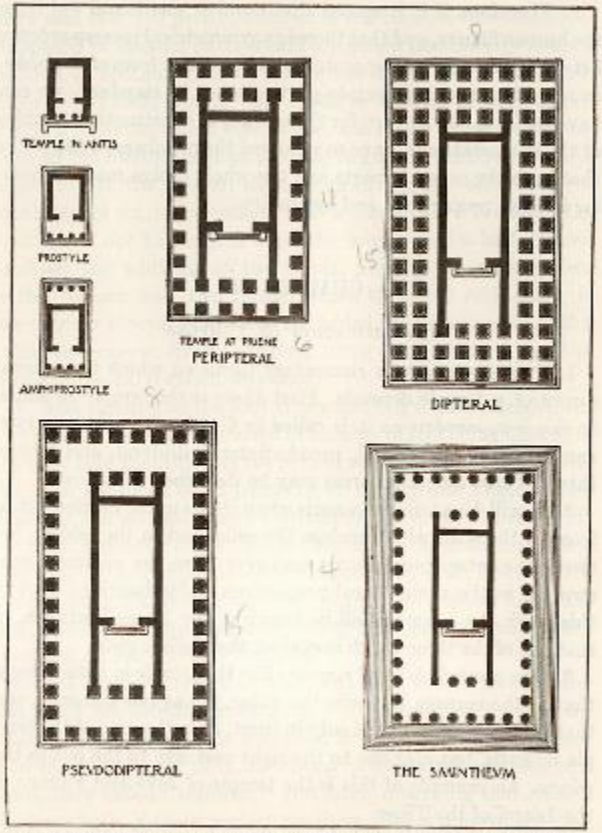
CHAPTER I

THE EDUCATION OF THE ARCHITECT

1. The architect should be equipped with knowledge of many branches of study and varied kinds of learning, for it is by his judgement that all work done by the other arts is put to test. This knowledge is the child of practice and theory. Practice is the continuous and regular exercise of employment where manual work is done with any necessary material according to the design of a drawing. Theory, on the other hand, is the ability to demonstrate and explain the productions of dexterity on the principles of proportion.

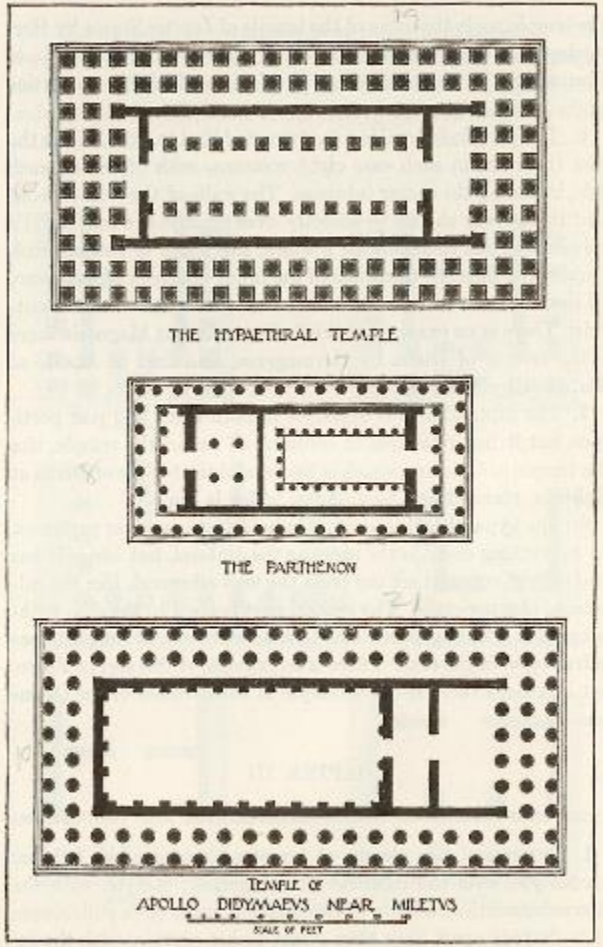
2. It follows, therefore, that architects who have aimed at acquiring manual skill without scholarship have never been able to reach a position of authority to correspond to their pains, while those who relied only upon theories and scholarship were obviously hunting the shadow, not the substance. But those who have a thorough knowledge of both, like men armed at all points, have the sooner attained their object and carried authority with them.

3. In all matters, but particularly in architecture, there are these two points: — the thing signified, and that which gives it its significance. That which is signified is the subject of which we may be speaking; and that which gives significance is a demonstration on scientific principles. It appears, then, that one who professes himself an architect should be well versed in both directions. He ought, therefore, to be both naturally gifted and amenable to instruction. Neither natural ability without instruction nor instruction without natural ability can make the perfect artist. Let him be educated, skilful with the pencil, instructed in geometry, know much history, have followed the philosophers with attention, understand music, have some knowledge of medi-



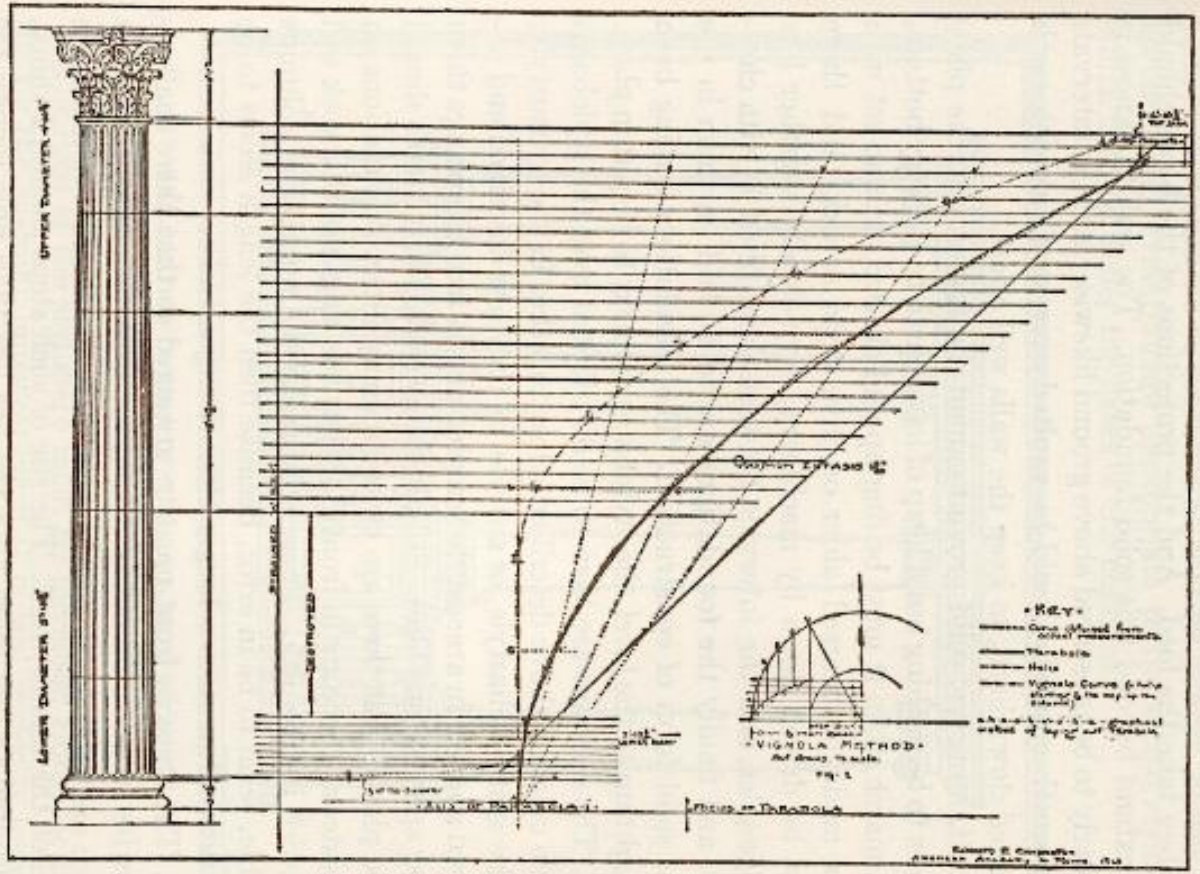
THE CLASSIFICATION OF TEMPLES ACCORDING TO THE ARRANGEMENTS OF THE COLONNADES

umns. Let the columns be so placed as to leave a space, the width of an intercolumniation, all round between the walls and the rows of columns on the outside, thus forming a walk round the cella of



THE HYPAETHRAL TEMPLE OF VITRUVIUS COMPARED WITH THE PARTHENON AND THE TEMPLE OF APOLLO NEAR MILETUS

1

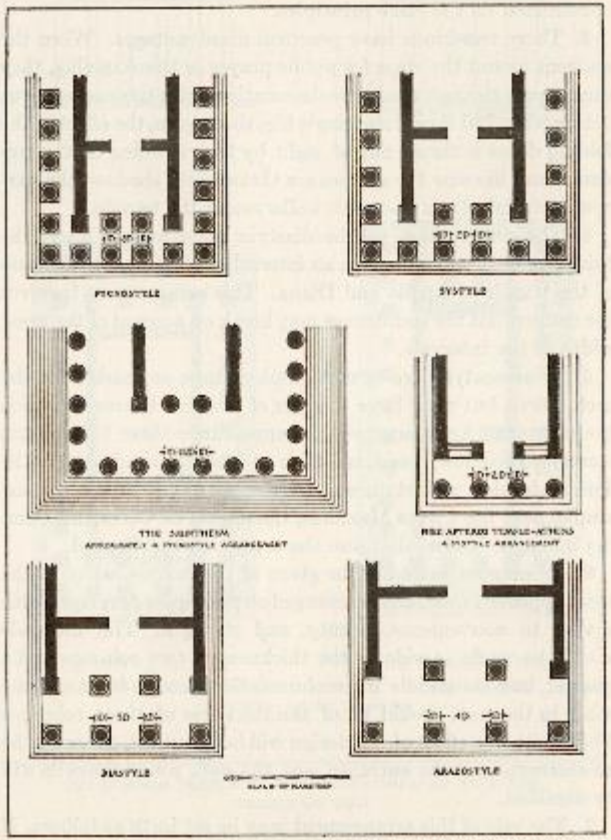


2

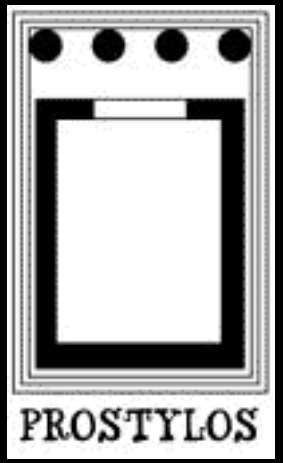
THE ENTASIS OF COLUMNS

1. The entasis as given by Fra Giocondo in the edition of 1511.
2. The entasis from the temple of Mars Ultor in Rome compared with Vignola's rule for entasis.

2. The pycnostyle is a temple in an intercolumniation of which the thickness of a column and a half can be inserted: for example, the temple of the Divine Caesar, that of Venus in Caesar's forum, and others constructed like them. The systyle is a temple in which

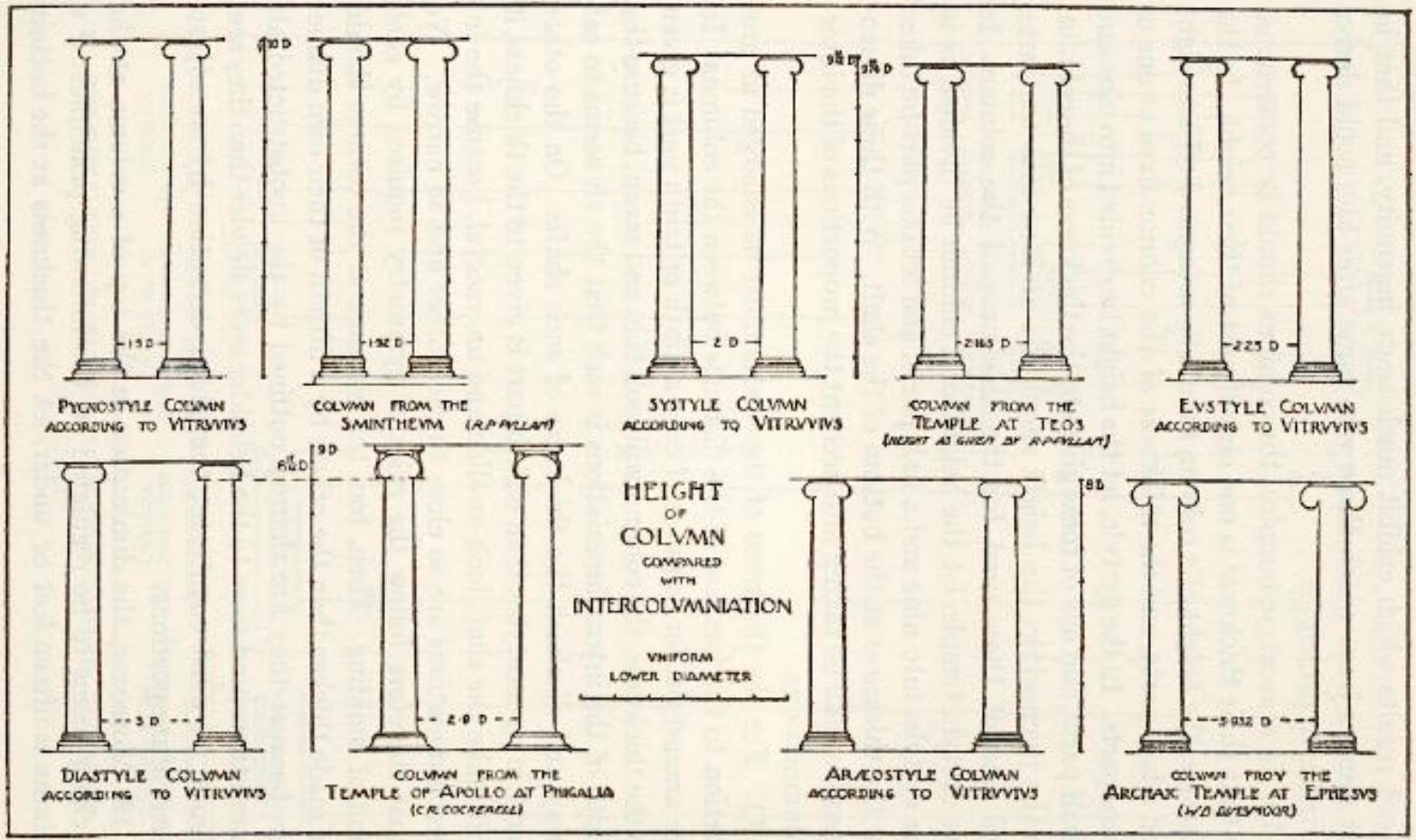


THE CLASSIFICATION OF TEMPLES ACCORDING TO INTERCOLUMNIATION

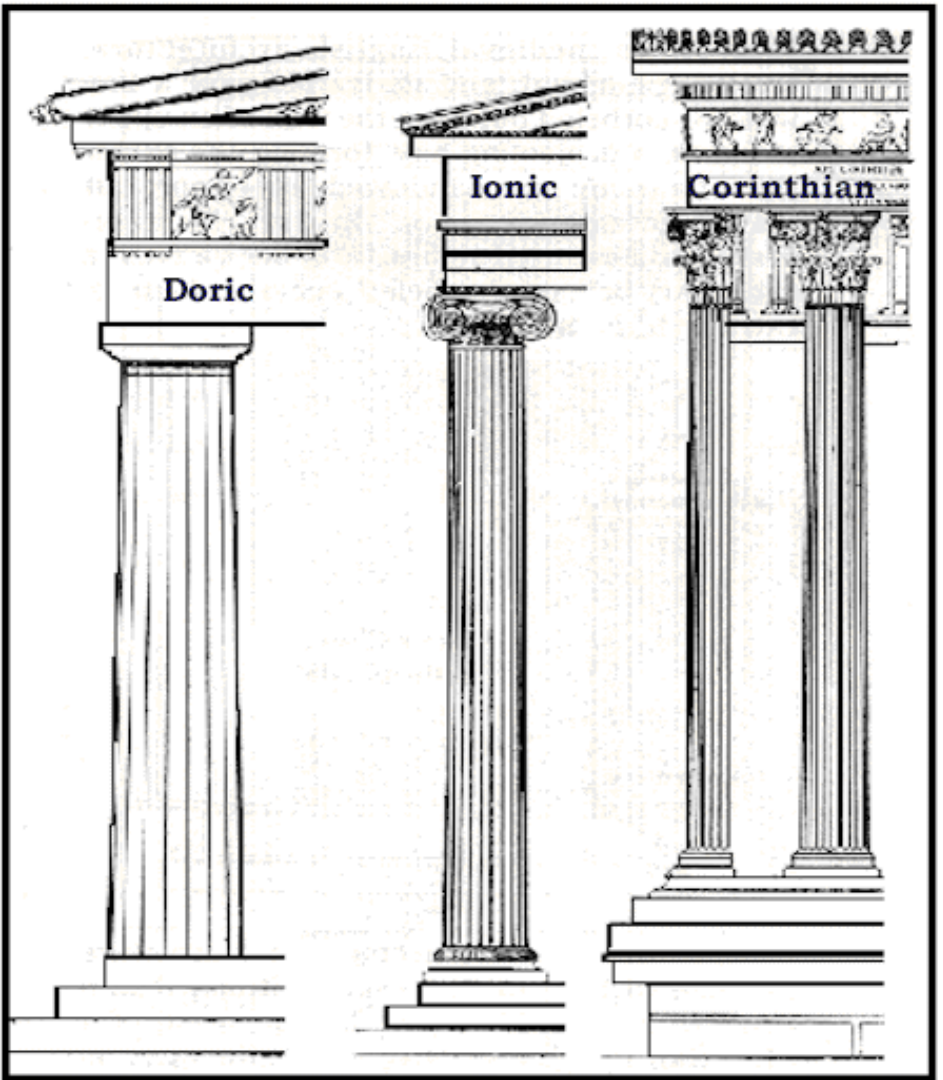


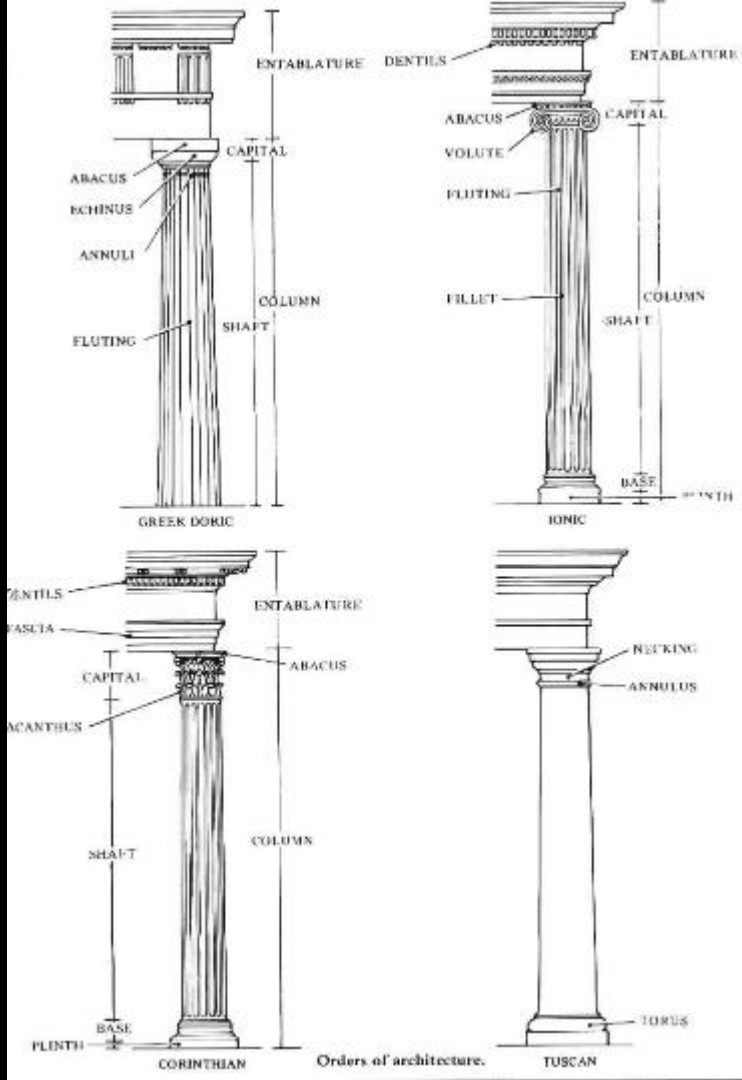

Temple of Portunus
Rome, Italy
3rd Century BCE

Temple of Hercules Victor
Rome, Italy
2nd Century BCE



VITRUVIUS' RULES FOR THE DIAMETER AND HEIGHT OF COLUMNS IN THE DIFFERENT CLASSES OF TEMPLE COMPARED WITH ACTUAL EXAMPLES


Doric
Ionic
Corinthian


ENTABLATURE
CAPITAL
ABACUS
ECHINUS
ANNULI
COLUMN
SHAFT
FLUTING
GREEK DORIC
DENTILS
ENTABLATURE
ABACUS
CAPITAL
VOLUTE
FLUTING
FILLET
COLUMN
SHAFT
BASE
IONIC
ENTABLATURE
ABACUS
CAPITAL
ACANTHUS
SHAFT
COLUMN
BASE
PLINTH
CORINTHIAN
NECKING
ANNULUS
TORUS
TUSCAN
Orders of architecture.


Temple of Saturn
Roman Forum
497 BCE (contested)

Stone: From Technique to Technology

Part 2: From Late Roman to Gothic

The Classical Style

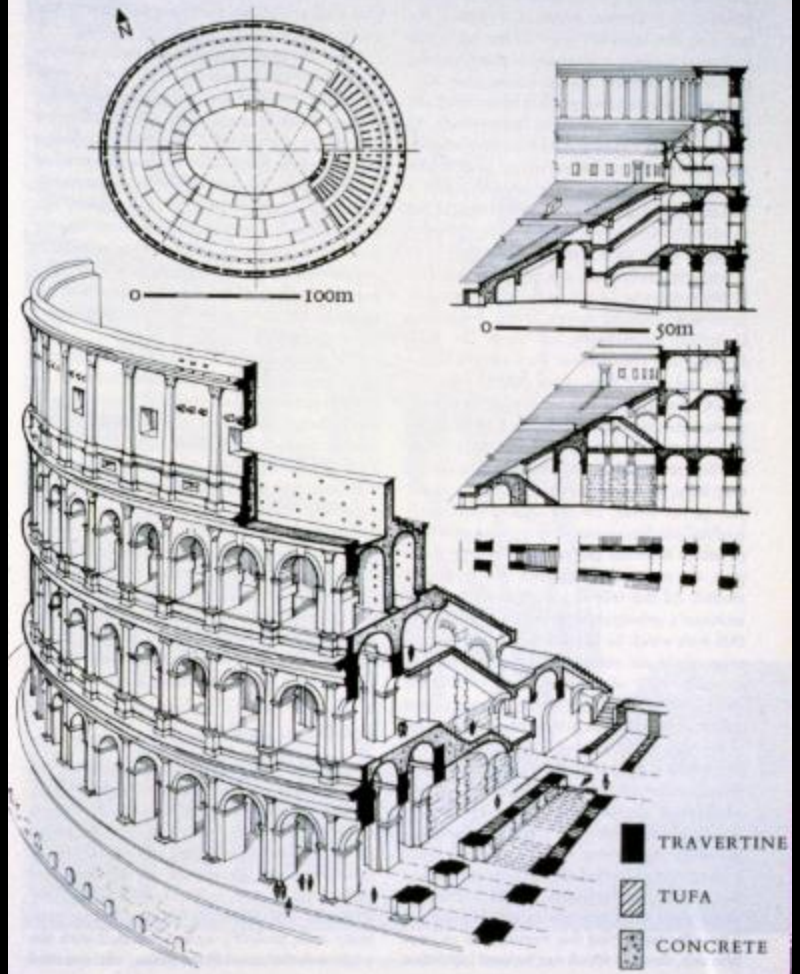
–

used ROUND arches

Stoa of Eumens
Acropolis, Athens
197 BCE

Coliseum/Flavian Amphitheatre
Rome, Italy
70 CE

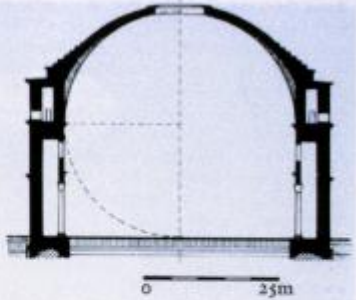
31. Rome, Amphitheatrum Flavium (Colosseum), inaugurated in 80.
Plans, sections, and sectional view

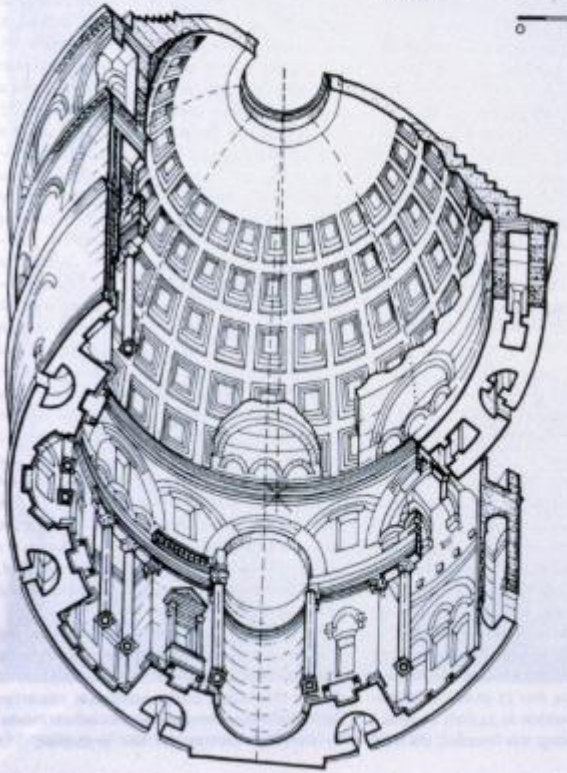


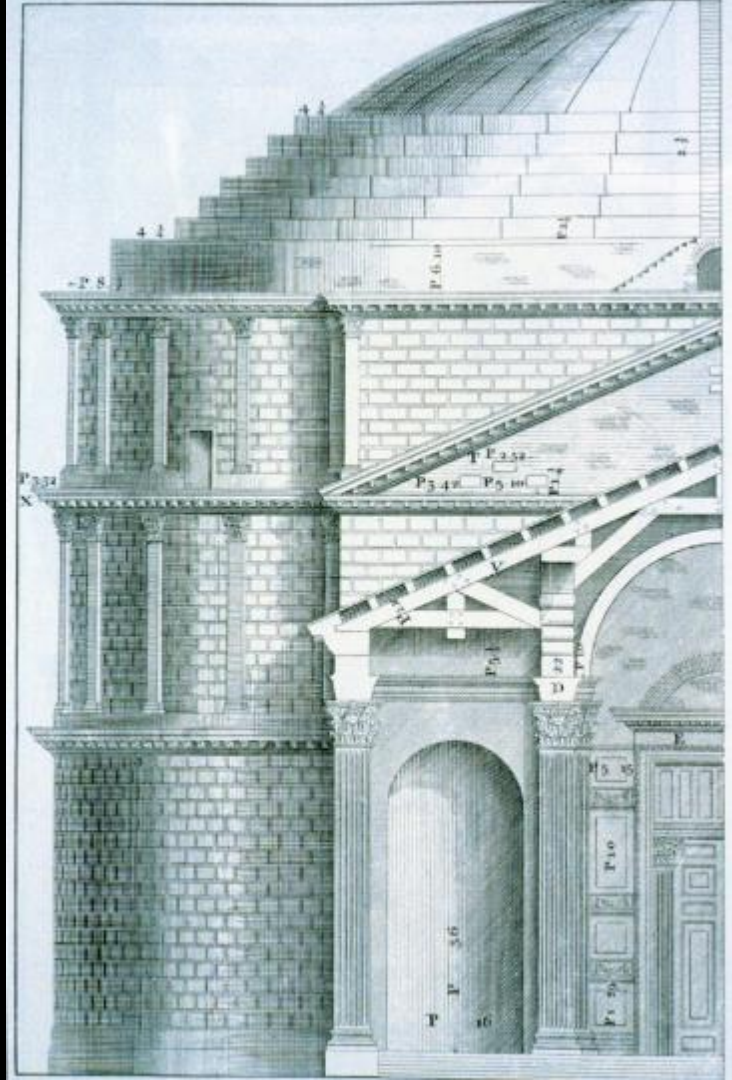
Palatine Hill
Rome, Italy

Pantheon
Rome, Italy
113 CE

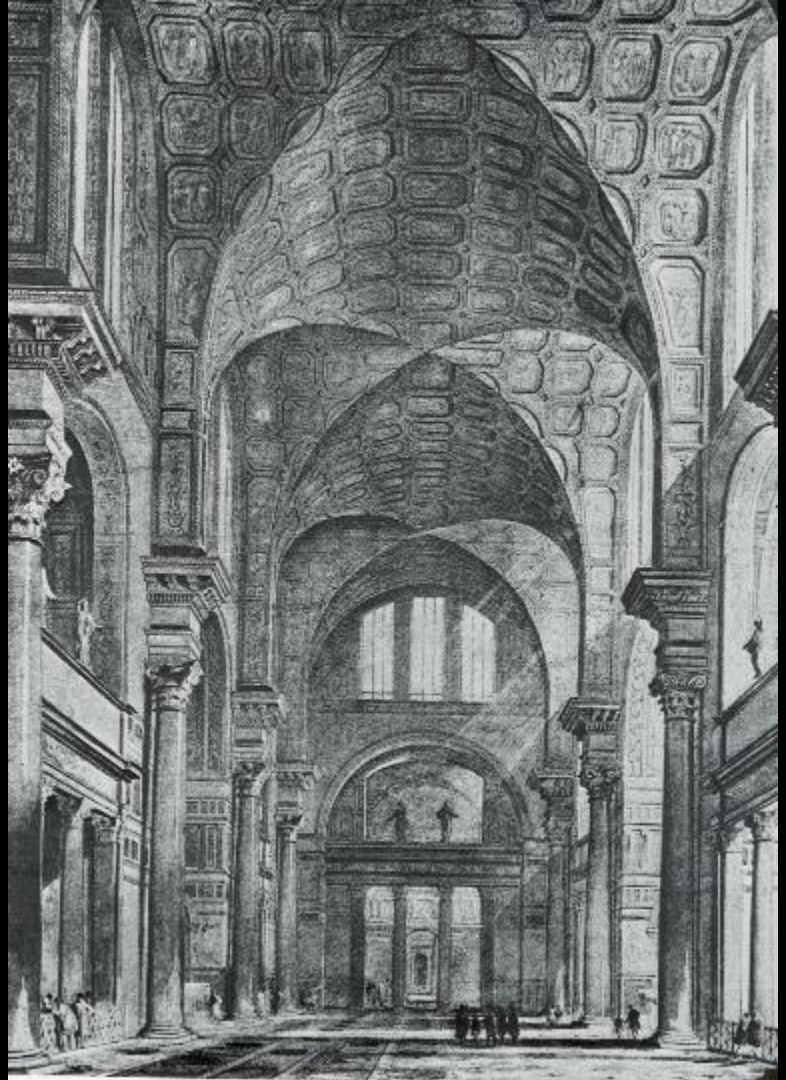
54. Rome, Pantheon, *c.* 118–*c.* 128.
Axonometric view and section. The stippled area in the section (here shown slightly exaggerated) represents the masonry added below the structural intrados of the dome so as to complete the visual curvature of the coffering



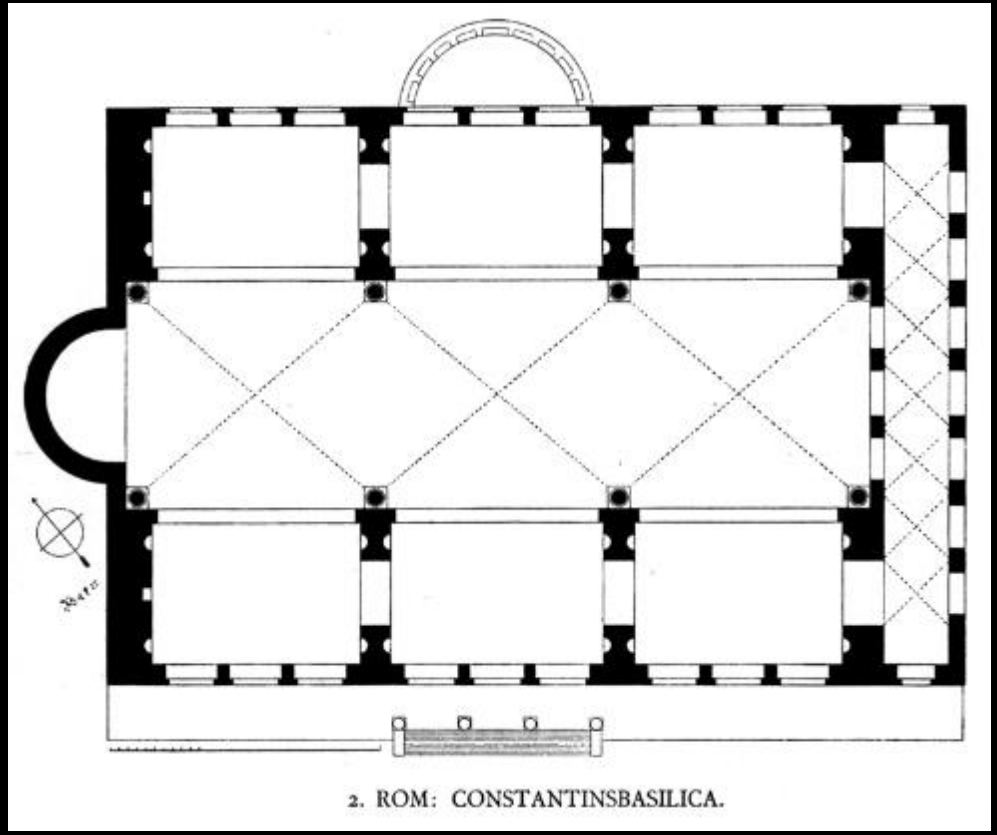





Baths of Caracalla
Rome, Italy
212 CE



Basilica of Maxentius and Constantine
Rome, Italy
312 CE

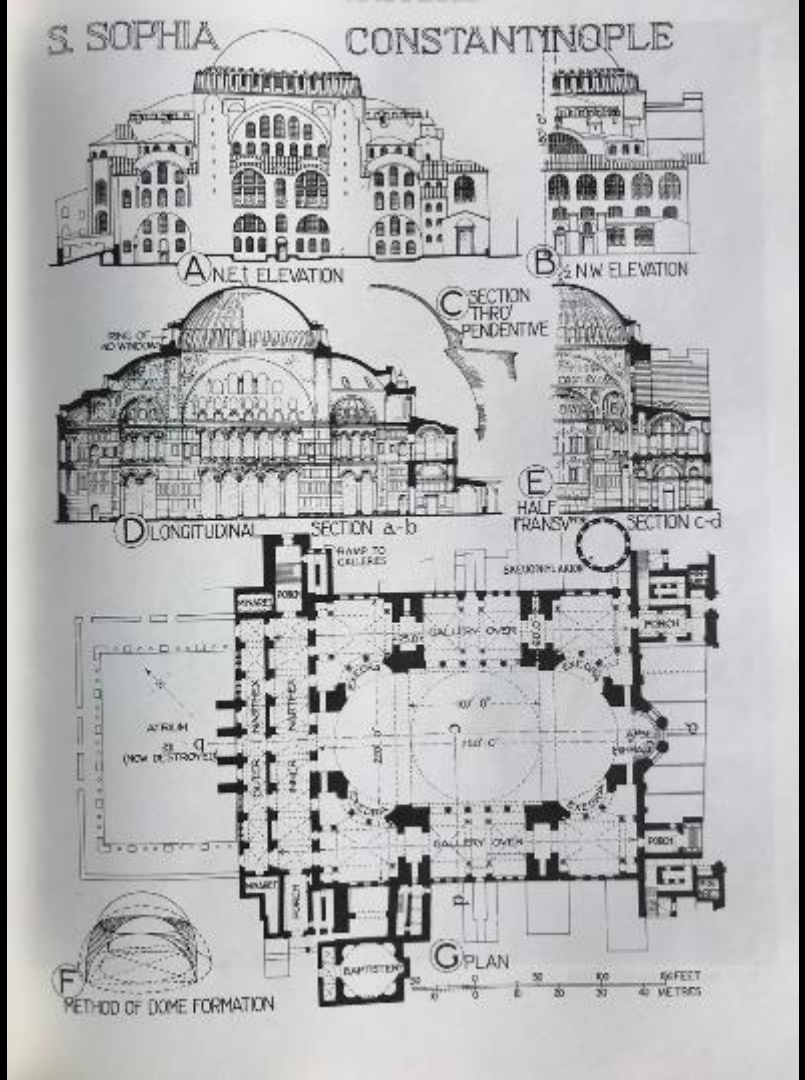


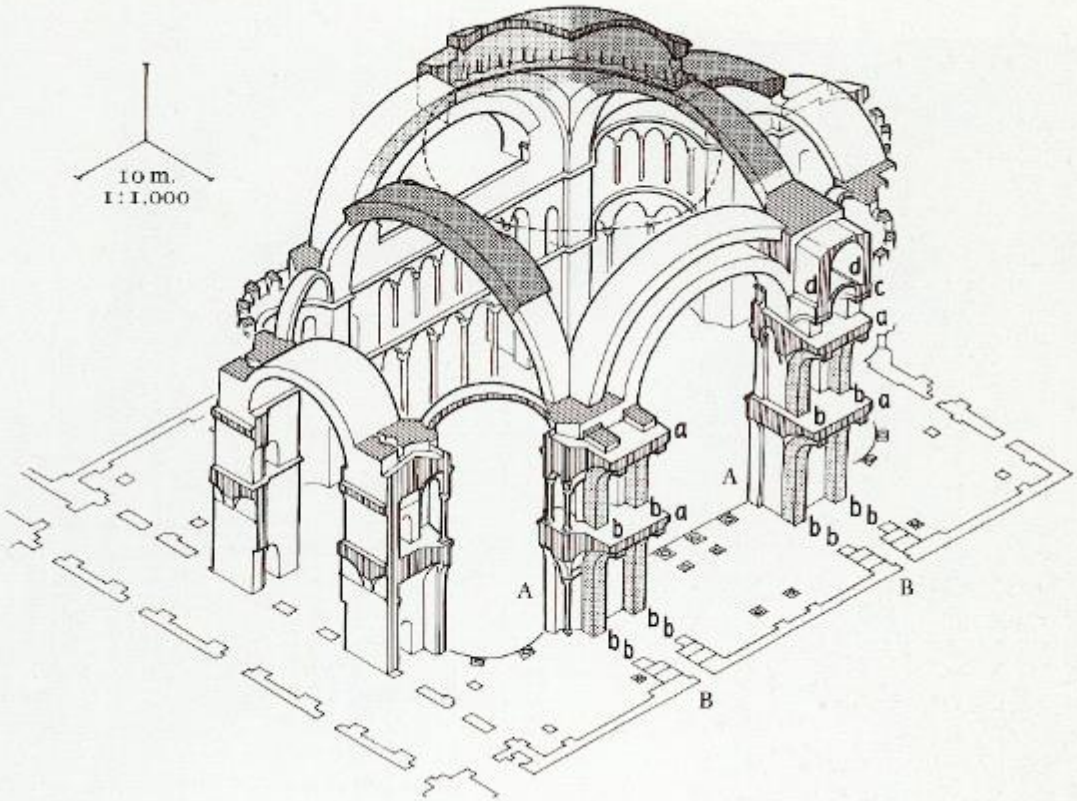
2. ROM: CONSTANTINSBASILICA.

Arch of Septimus Severus
Roman Forum
203CE

Arch of Constantine
Roman Forum
315 CE

Hagia Sophia
Constantinople/Istanbul, Turkey
537 CE


S. SOPHIA CONSTANTINOPLE
A N.E.T ELEVATION
B ½ N.W. ELEVATION
C SECTION THRO' PENDENTIVE
D LONGITUDINAL SECTION a-b
E HALF TRANSV. SECTION c-d
F METHOD OF DOME FORMATION
G PLAN
RAMP TO GALLERIES
GALLERY OVER
PORCH
ATRIUM
NARTHEX
EXONARTHEX
BAPTISTERY
FEET
METRES

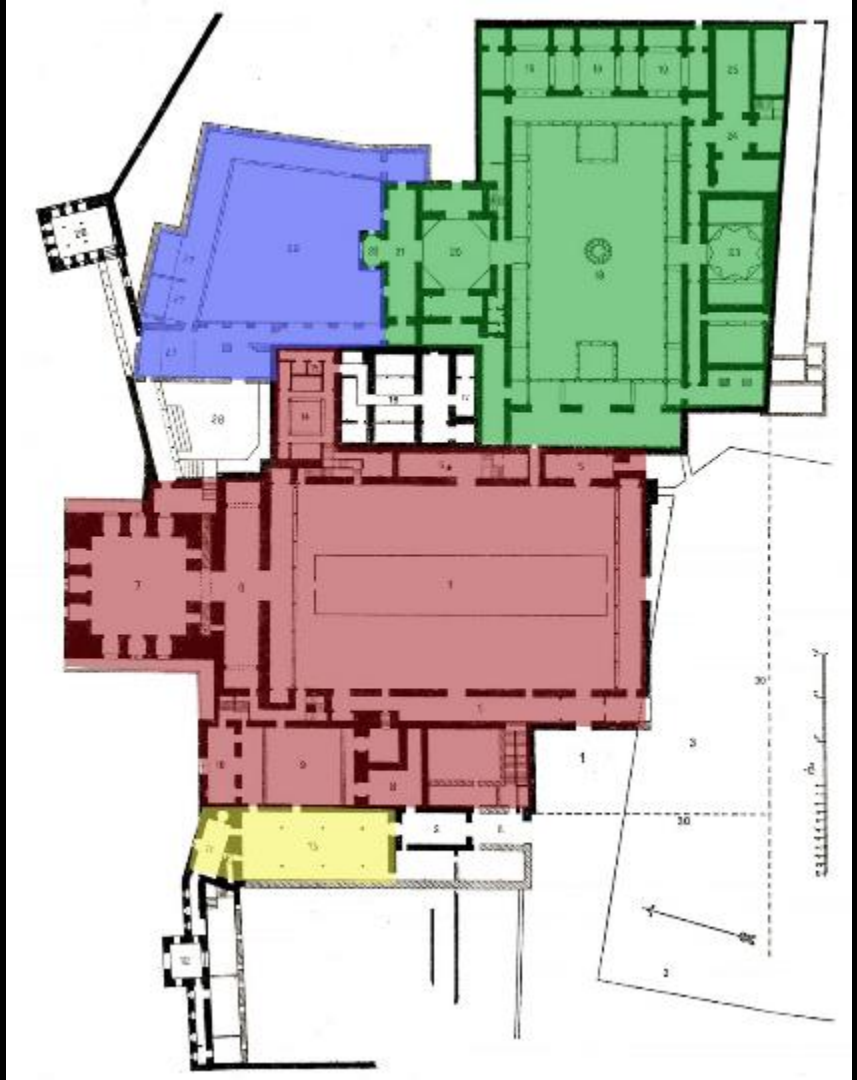


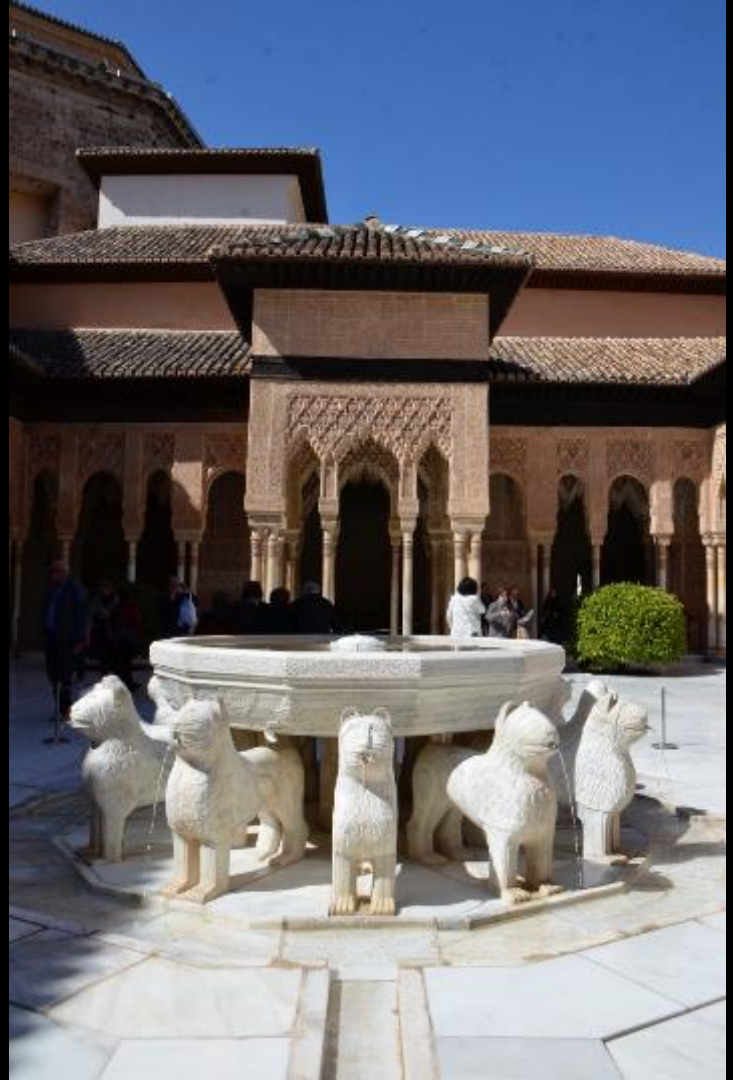
16.6 St Sophia, Istanbul, part cut-away isometric sketch from the south-west showing the basic structure as now existing. Lightly-stippled elements are sixth-century additions to, or, in the case of the dome, modified reconstructions of, the original form. Heavily-stippled elements are later reconstructions, tenth-century at the west and fourteenth-century at the east.


St. Mark's Basilica
Venice, Italy
978 CE

Mosque-Cathedral of Cordoba
Cordoba, Spain
784 (Islam) 1236 (Catholic)

The Alhambra Palace
Granada, Spain
Moorish
1333 CE

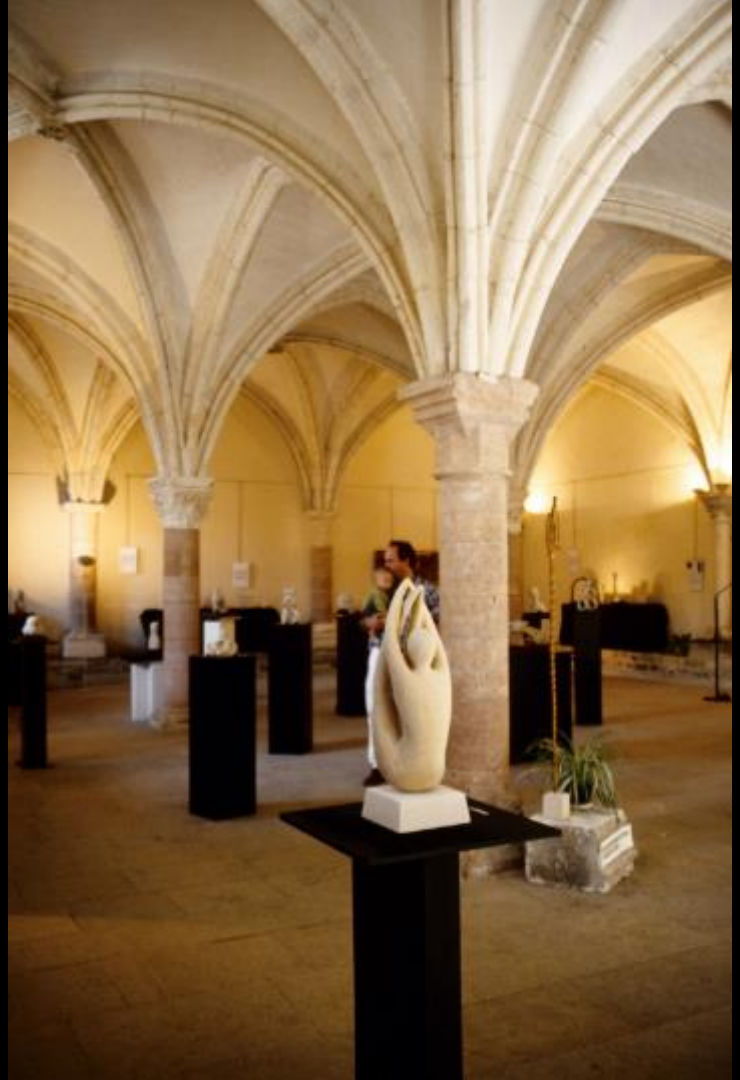


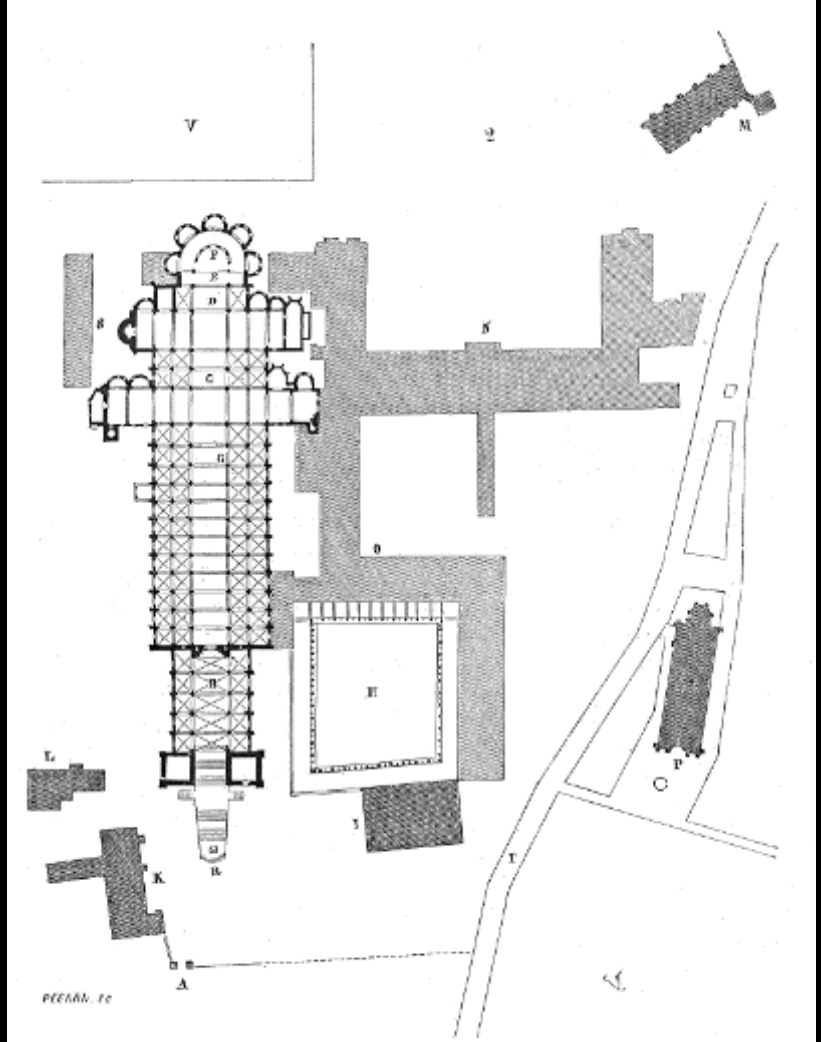


Medieval Architecture
Including
Romanesque and Gothic
round arches vs pointed arches
6th to 12th century

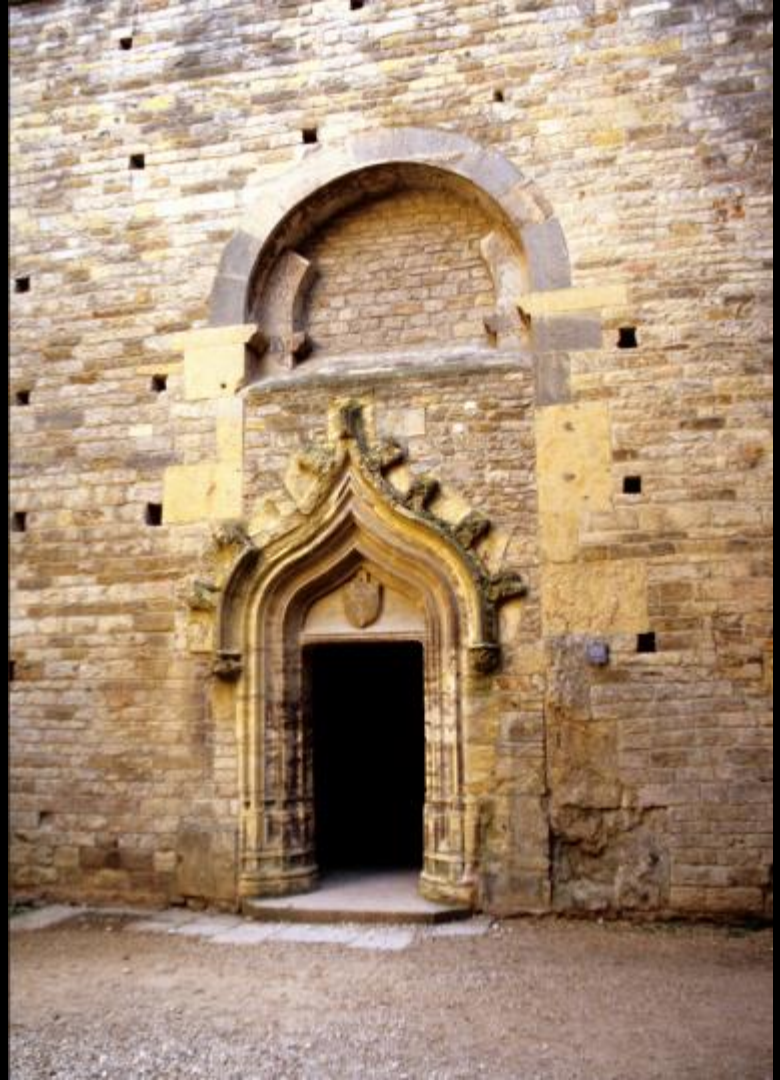
Chateau de Chillon
Montreux, Switzerland
Started 1005 CE

Saint-Philibert de Tournus
Tournus, France
11th century





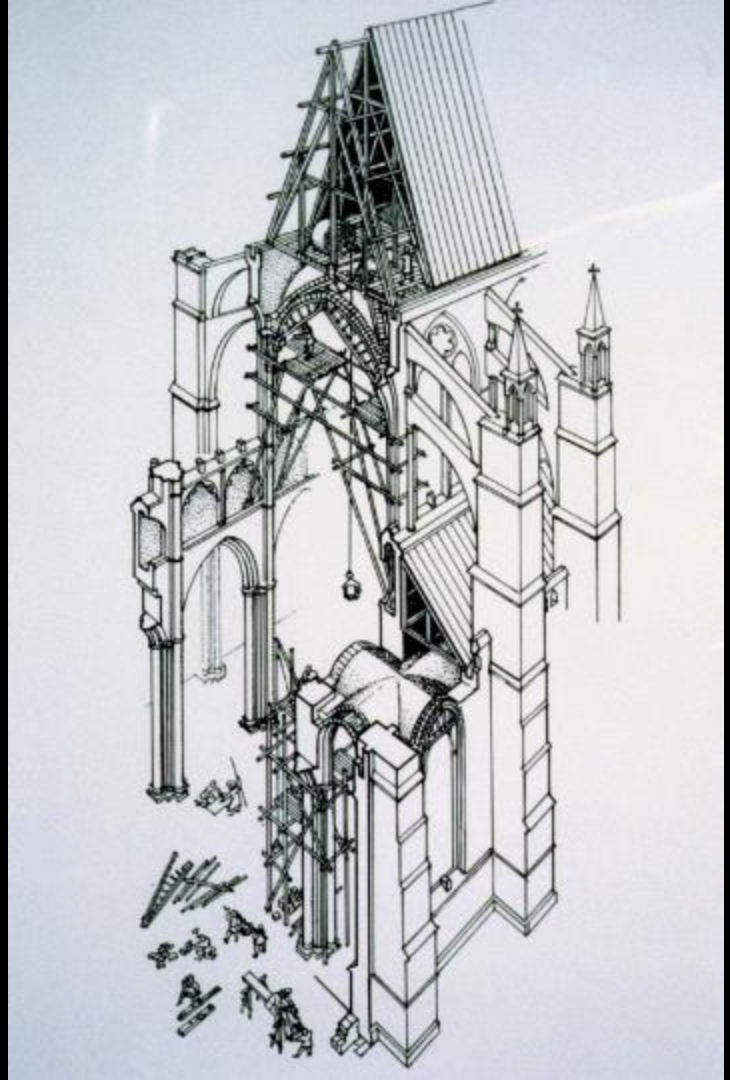
Cluny Abbey
Cluny, Saone-et-Loire,
France
12th century



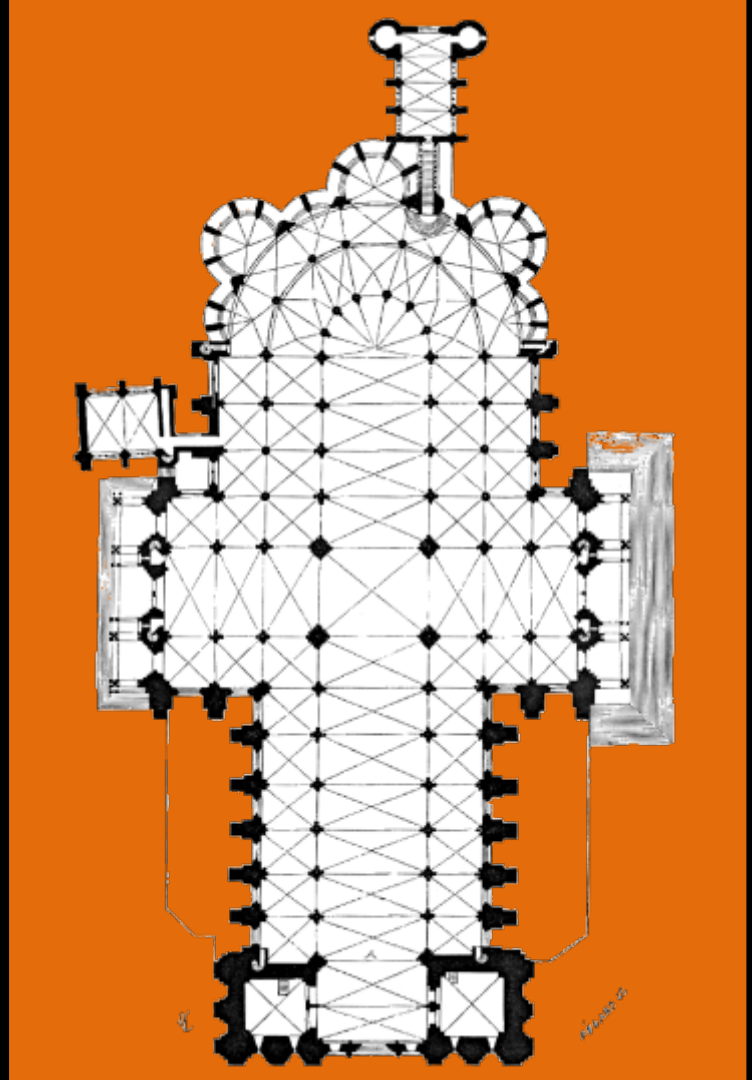
MEDIEVAL STRUCTURE:

THE GOTHIC VAULT

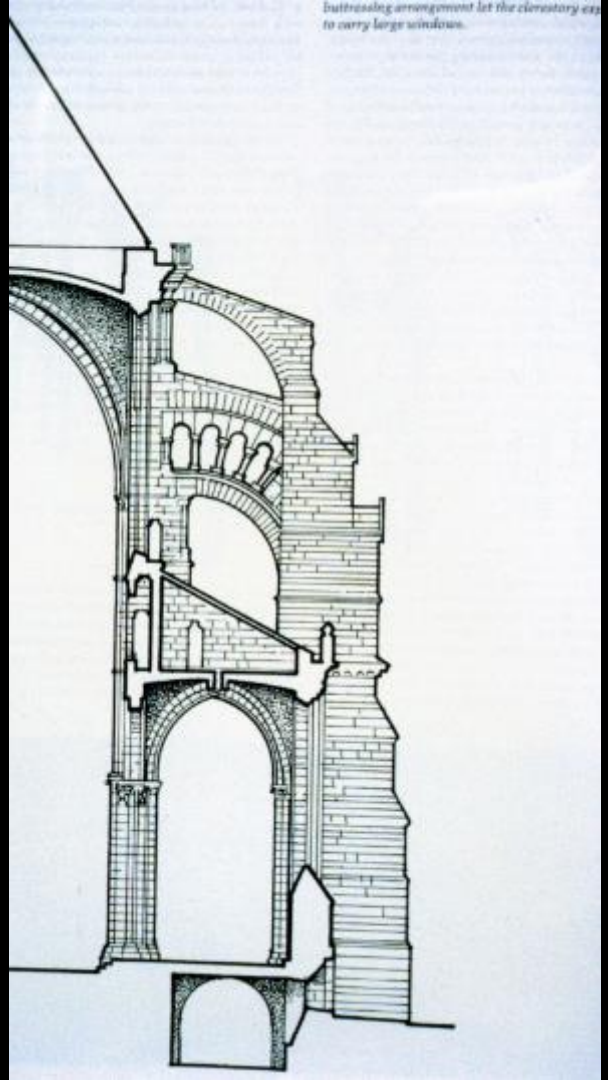
JAMES H. ACLAND

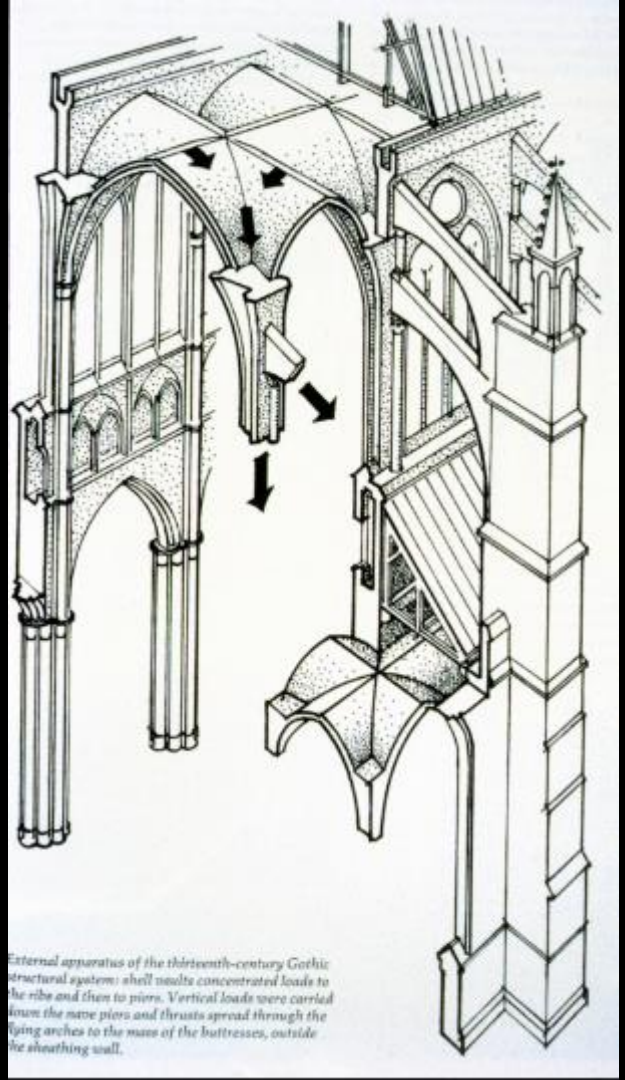


Chartres
Cathedral
Chartres, France
1194 CE



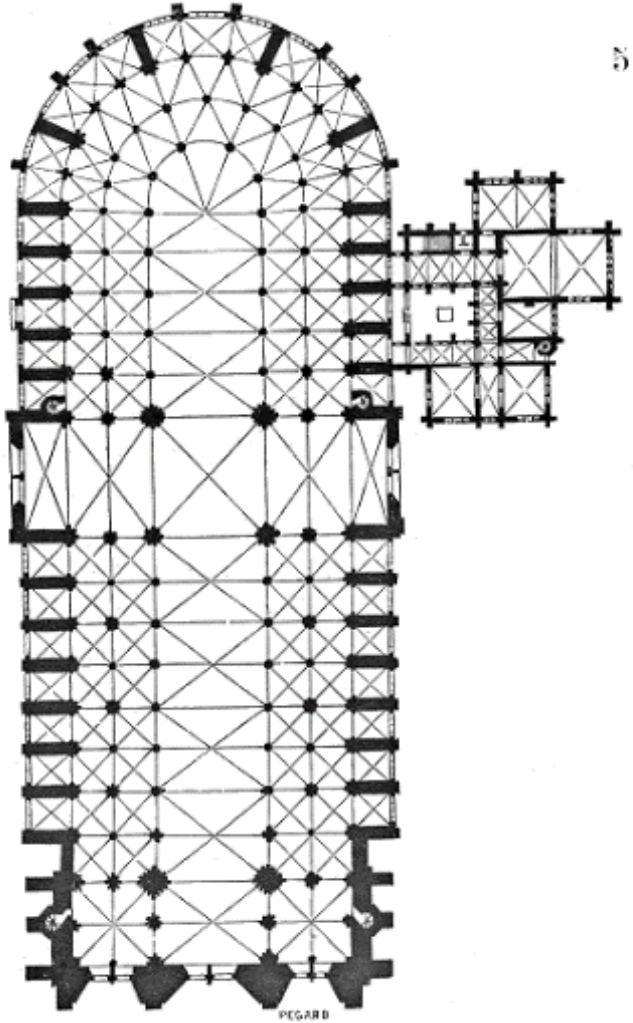
buttressing arrangement let the clerestory exp
to carry large windows.



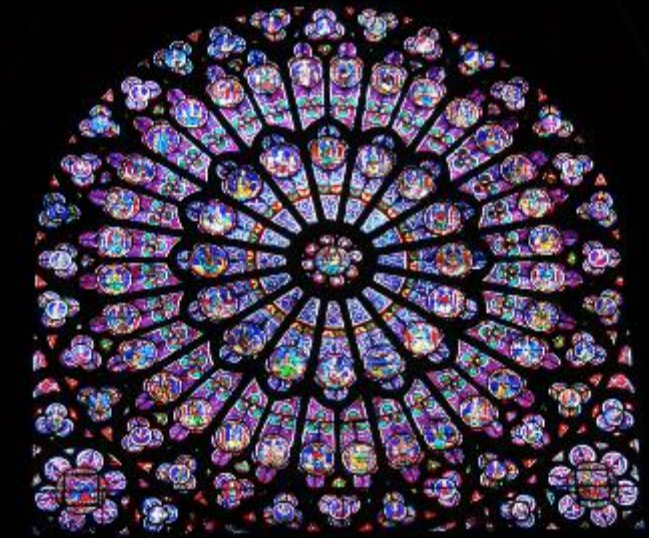


External apparatus of the thirteenth-century Gothic structural system: shell vaults concentrated loads to the ribs and then to piers. Vertical loads were carried down the nave piers and thrusts spread through the flying arches to the mass of the buttresses, outside the sheathing wall.

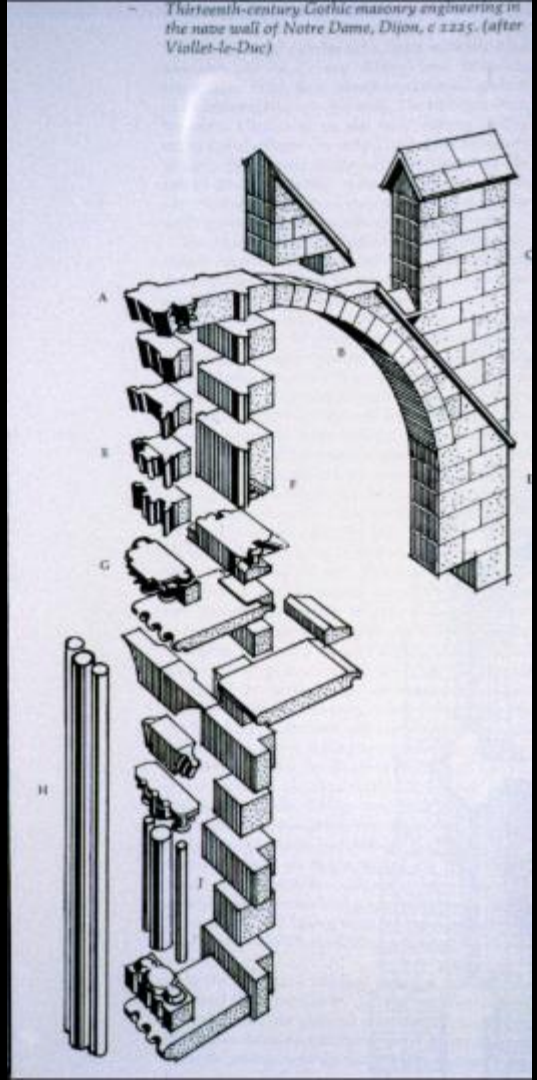
Notre-Dame de Paris
Paris, France
1163 CE



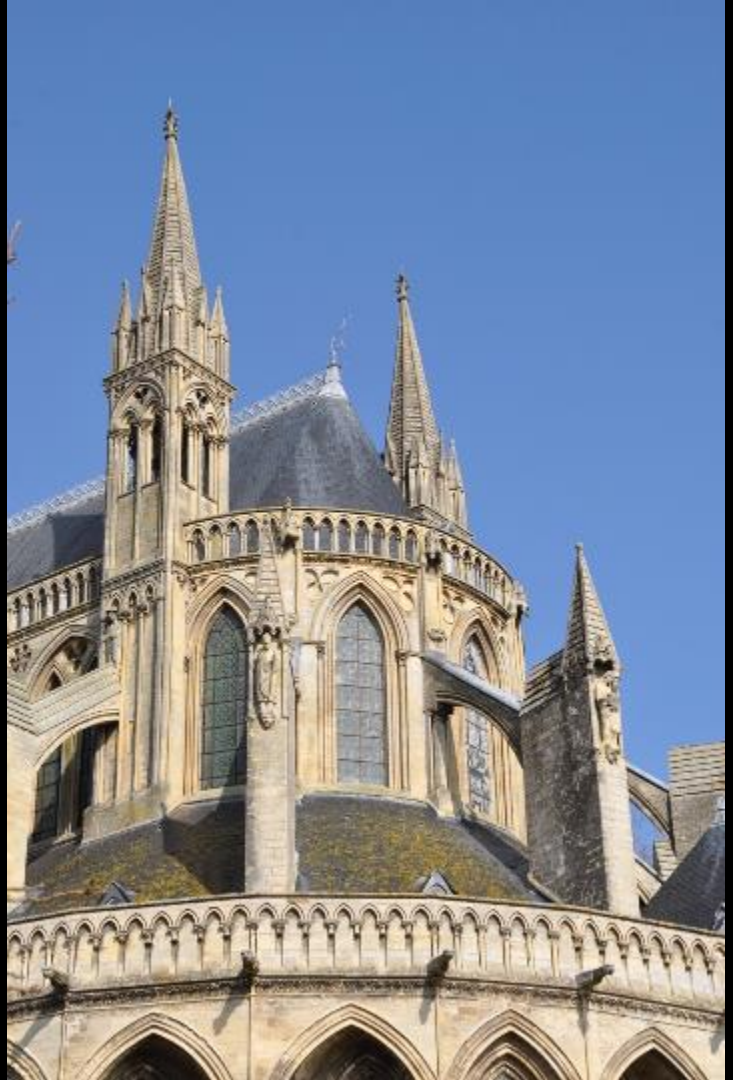
PEGARD



Thirteenth-century Gothic masonry engineering in the nave wall of Notre Dame, Dijon, c 1225. (after Viollet-le-Duc)



Cathedral at Bayeux, France
Norman-Romanesque Style
1077

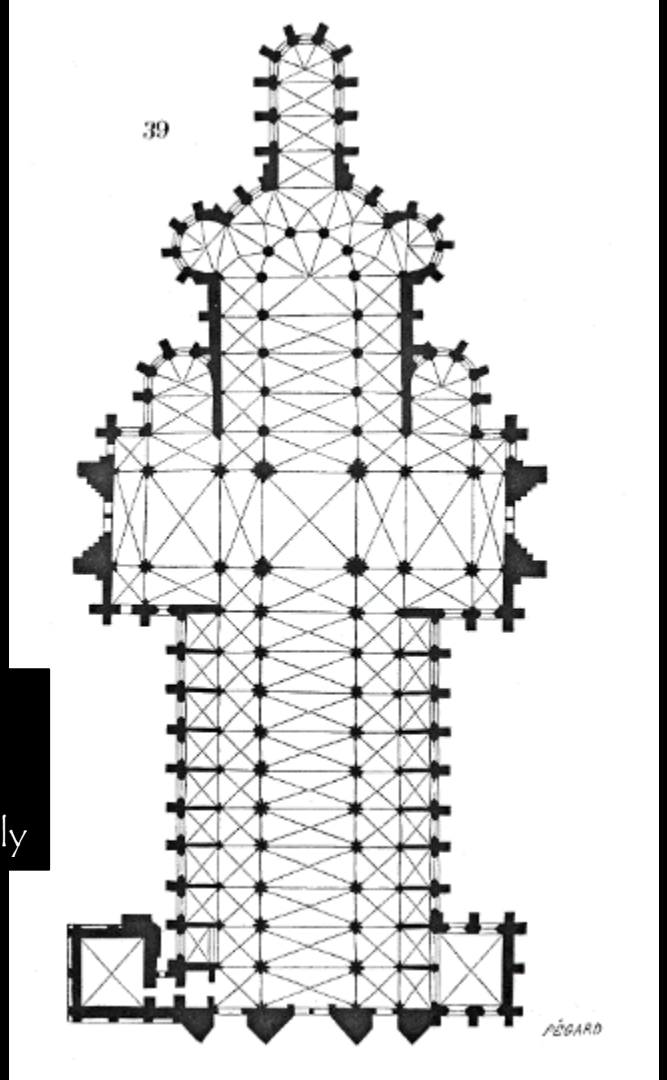


Bayeux Tapestry
1077

The Bayeux Tapestry is an embroidered cloth nearly 70 metres long and 50 centimetres tall that depicts the events leading up to the Norman conquest of England concerning William, Duke of Normandy, and Harold, Earl of Wessex, later King of England,
and culminating in the Battle of Hastings.


53

Rouen Cathedral
Rouen, France
High Gothic
1000 to 1500 approximately




Etam

Westminster Abbey
London, England
1245 CE


St. George's Chapel, Windsor Castle
Windsor, England
14th century