Structures & CLT (Cross Laminated Timber)

28th November 2019

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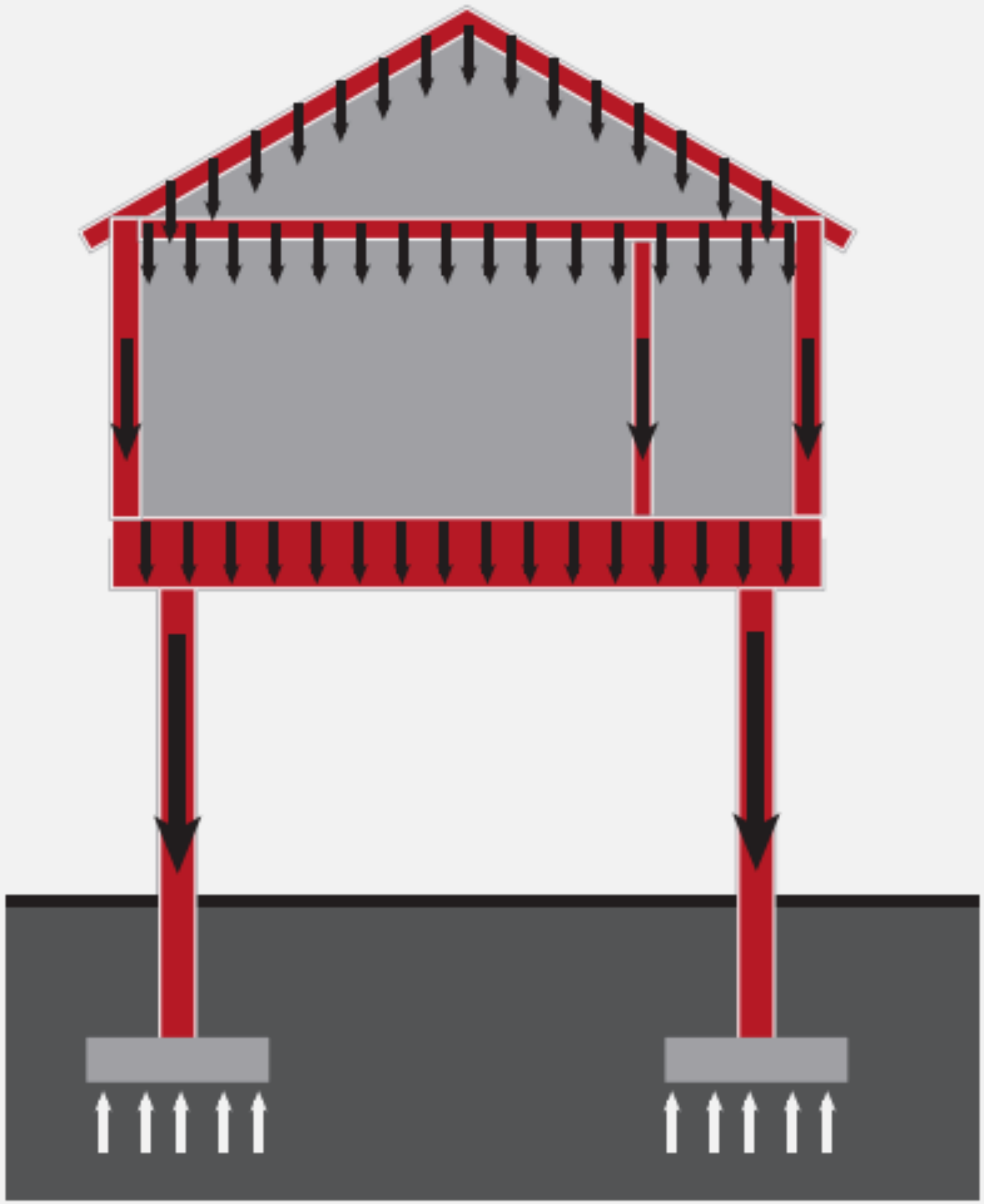
IT Sligo
An Institiúid Teicneolaíochta, Sligeach

Dead Loads

Structural Elements

Fixtures

Footings



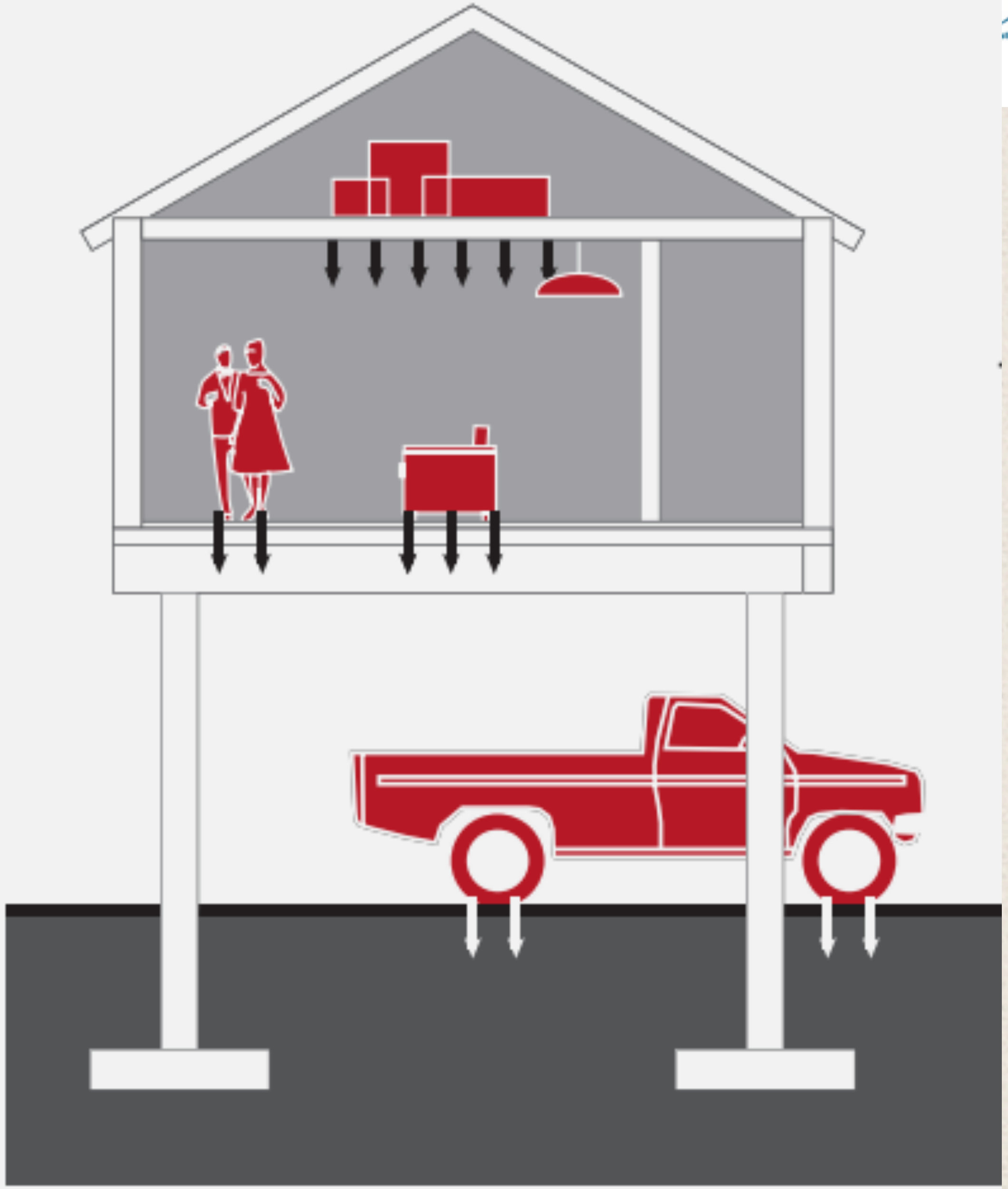
Live Loads

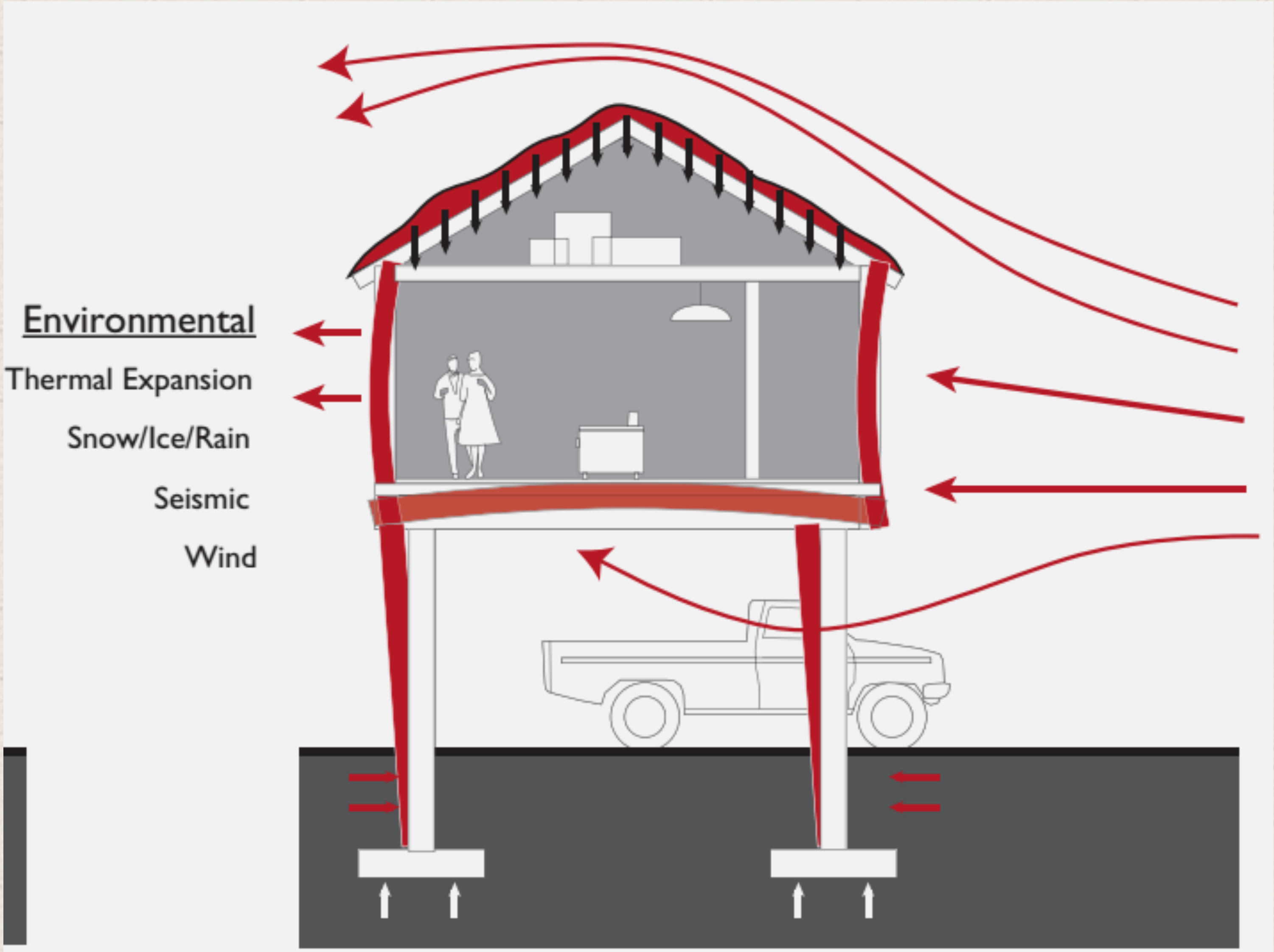
Occupants

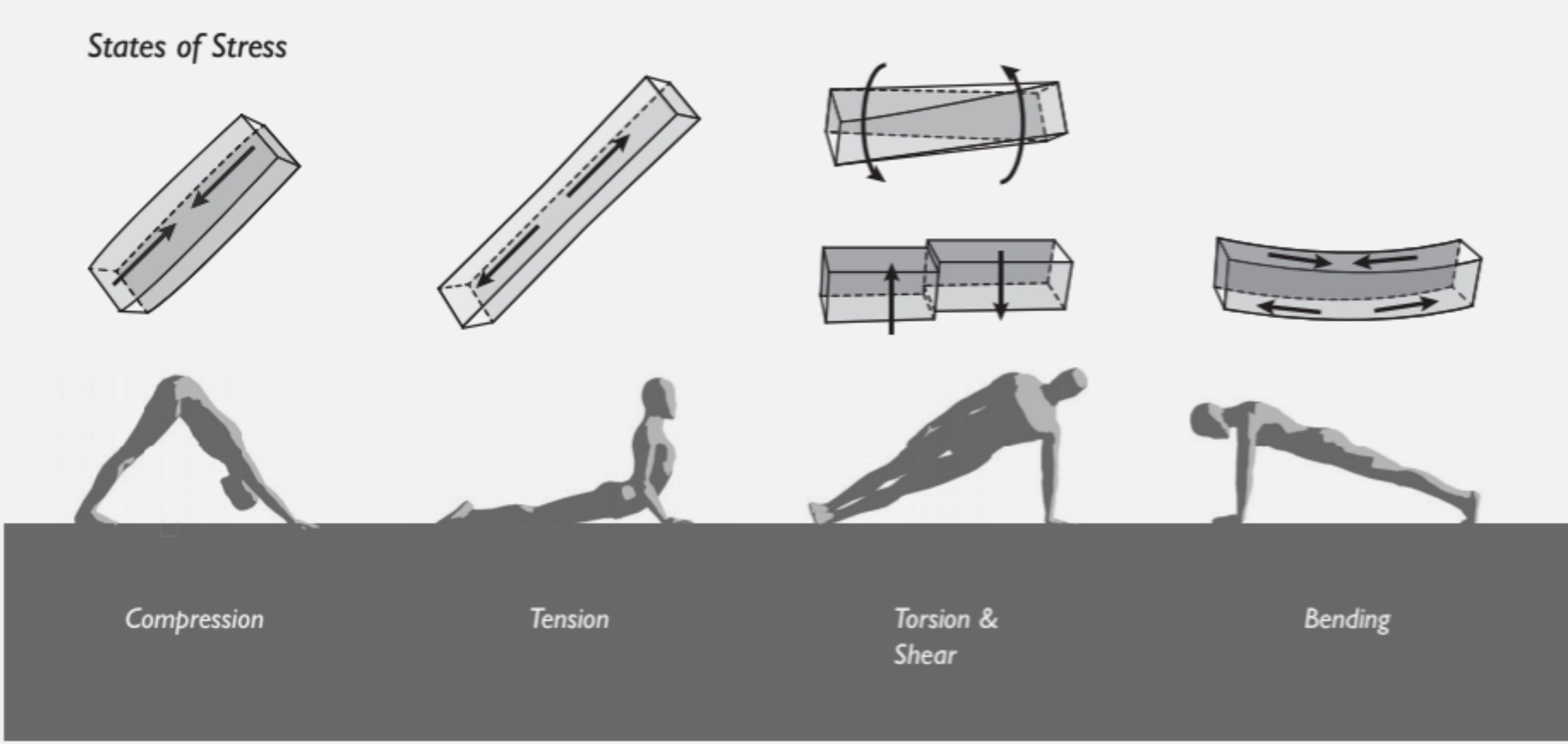
Furniture

Storage

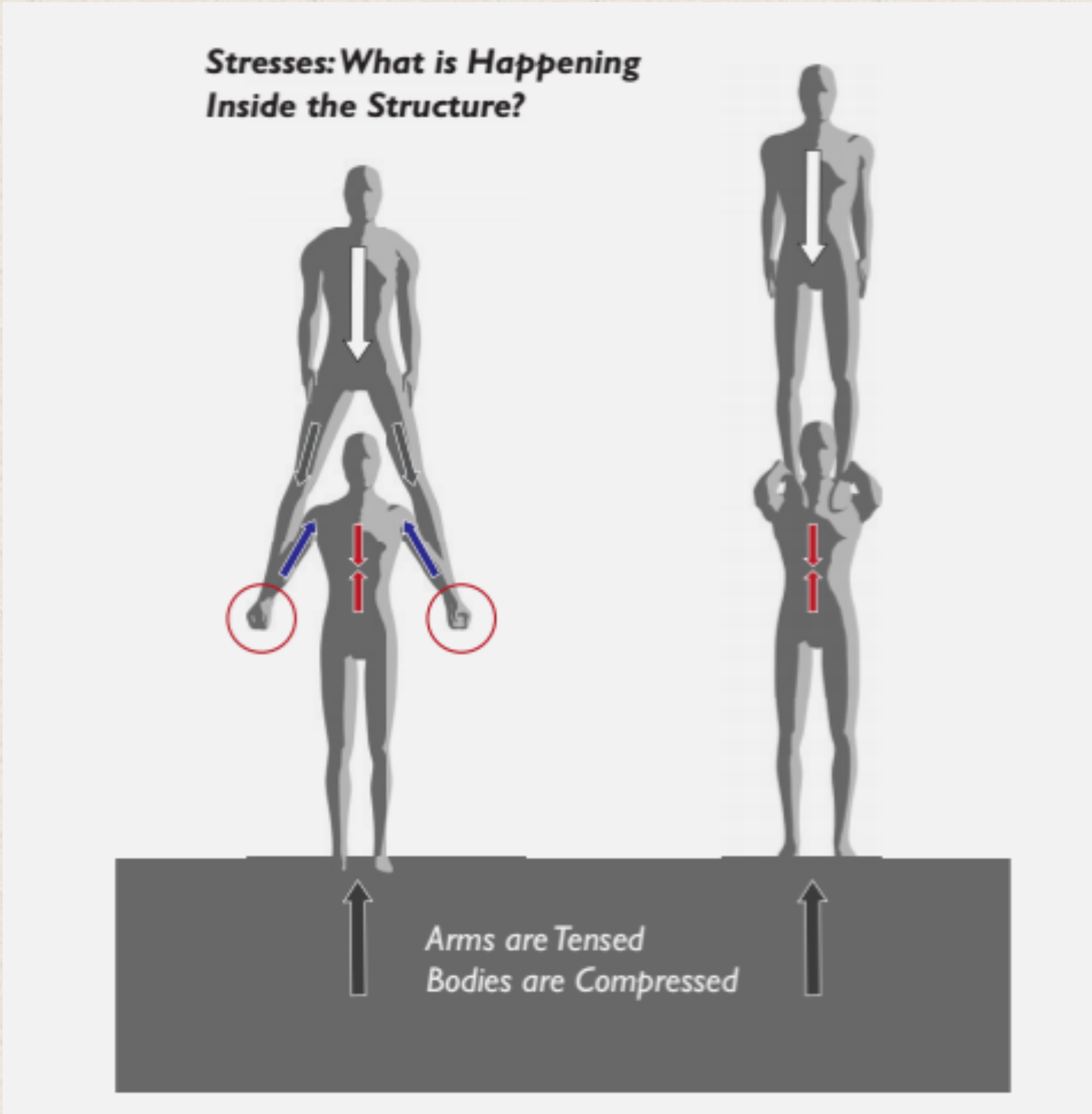
Vehicles




Environmental
Thermal Expansion
Snow/Ice/Rain
Seismic
Wind


States of Stress
Compression
Tension
Torsion & Shear
Bending

In the plank pose, your body is in bending and you feel the shear stress on the shoulders. If the heavy cat on your back shifts off to the side on your hip, your body may twist—this is torsion. Understanding these states of stress and how they feel is a good way of confirming what force vectors acting in a structure are doing. For example, consider supporting someone on your shoulders under compression or having them hang onto your ankles as you dangle, pulling you in tension—the amount of force in each scenario is the same, but the states of stress are different and your body will behave accordingly. (Figure 1.0.14)

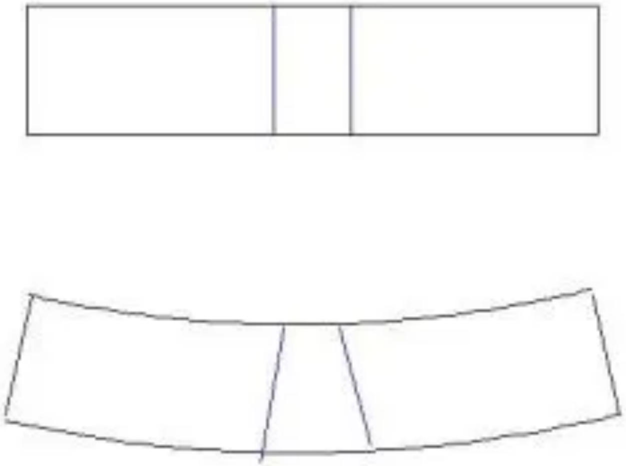

Stresses: What is Happening Inside the Structure?
Arms are Tensed
Bodies are Compressed

Take an eraser:

Draw 2 lines as shown

Bend the eraser

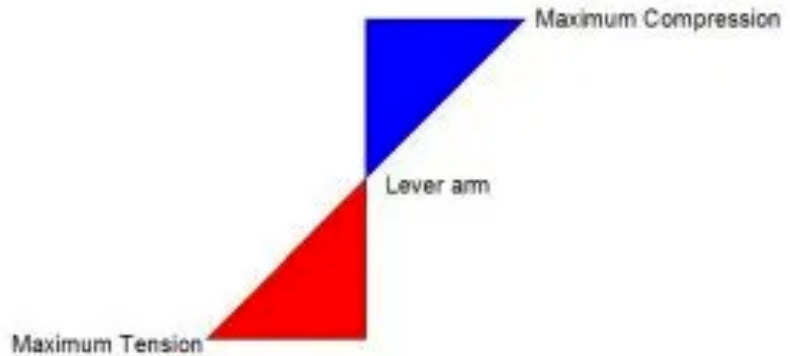
Watch how the lines get closer at the top, wider at the bottom but are the same at the centre:



Maximum tension occurs at the bottom and dissipates linearly to the centre

Maximum compression occurs at the top and dissipates linearly to the centre

The diagram below shows what's happening to these forces:



This is a 'moment' diagram

What we have here therefore is a *Lever Arm* “the tendency of a force to rotate an object about an axis” – for more information on Lever Arms CLICK HERE

These two forces (compression & tension) are acting in parallel and opposite each other; the amount of these forces and the distance between them (the lever arm) create a *bending moment*.

Bending Moment = The Force x The Lever arm

This lever arm is therefore critical in steelwork design; the larger the lever arm, the greater the span.

This is why columns and beams are the shape they are; with the flanges at the top and bottom, the centre of gravity of a beam moves to the top and bottom of the beam:

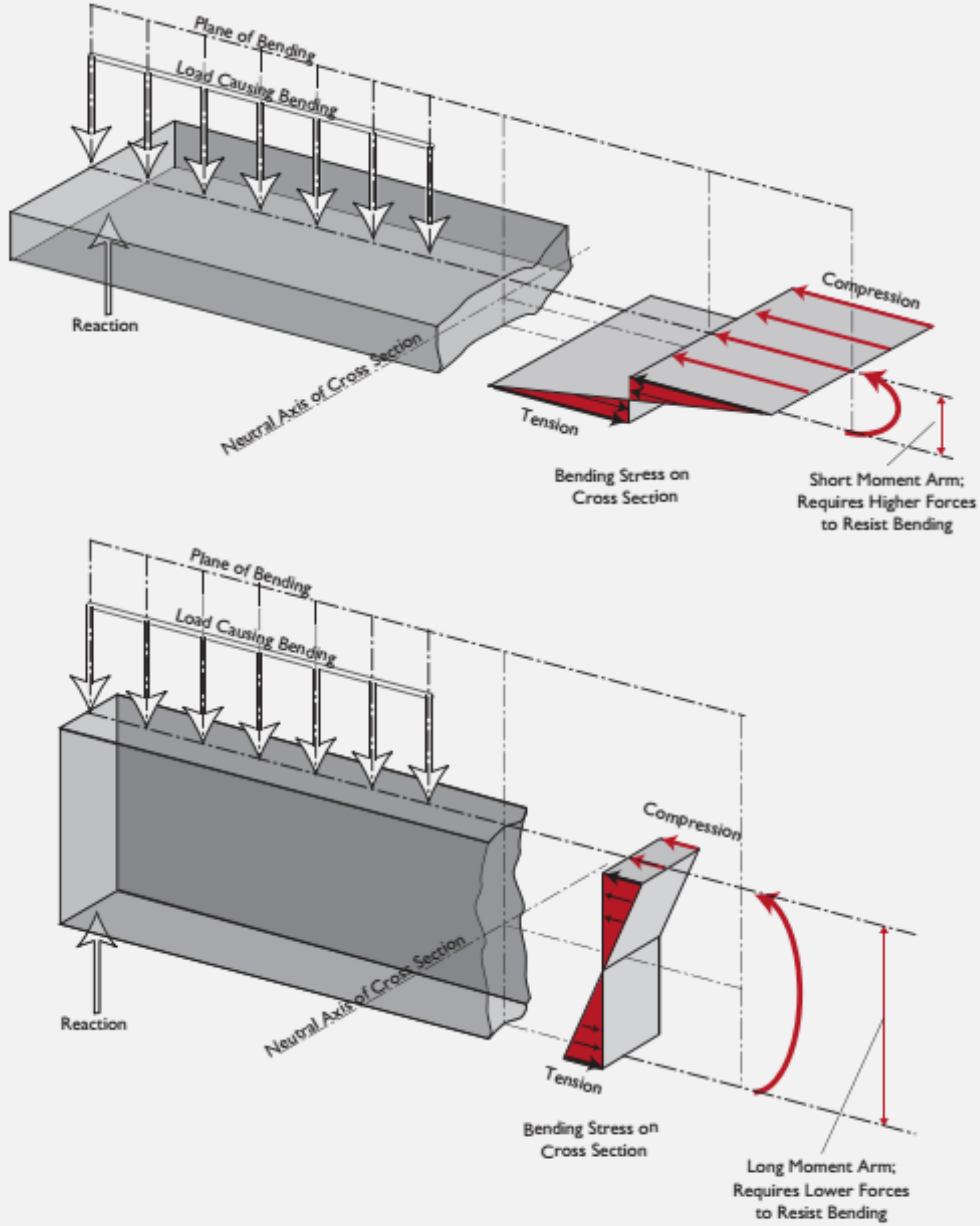
A beam's resisting moment depends on its depth and the distribution of its sectional area.

Stresses are resisted by cross-sectional area—the higher the force, the more area is needed

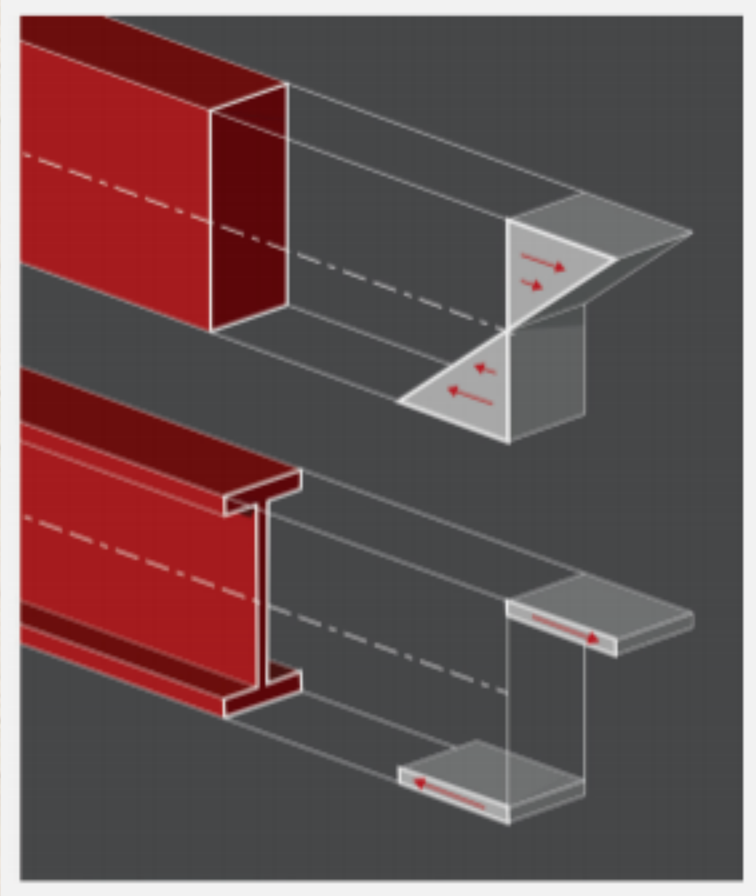
It makes sense to put the most area where the highest internal forces occur in our beams namely, at their top and bottom edges.

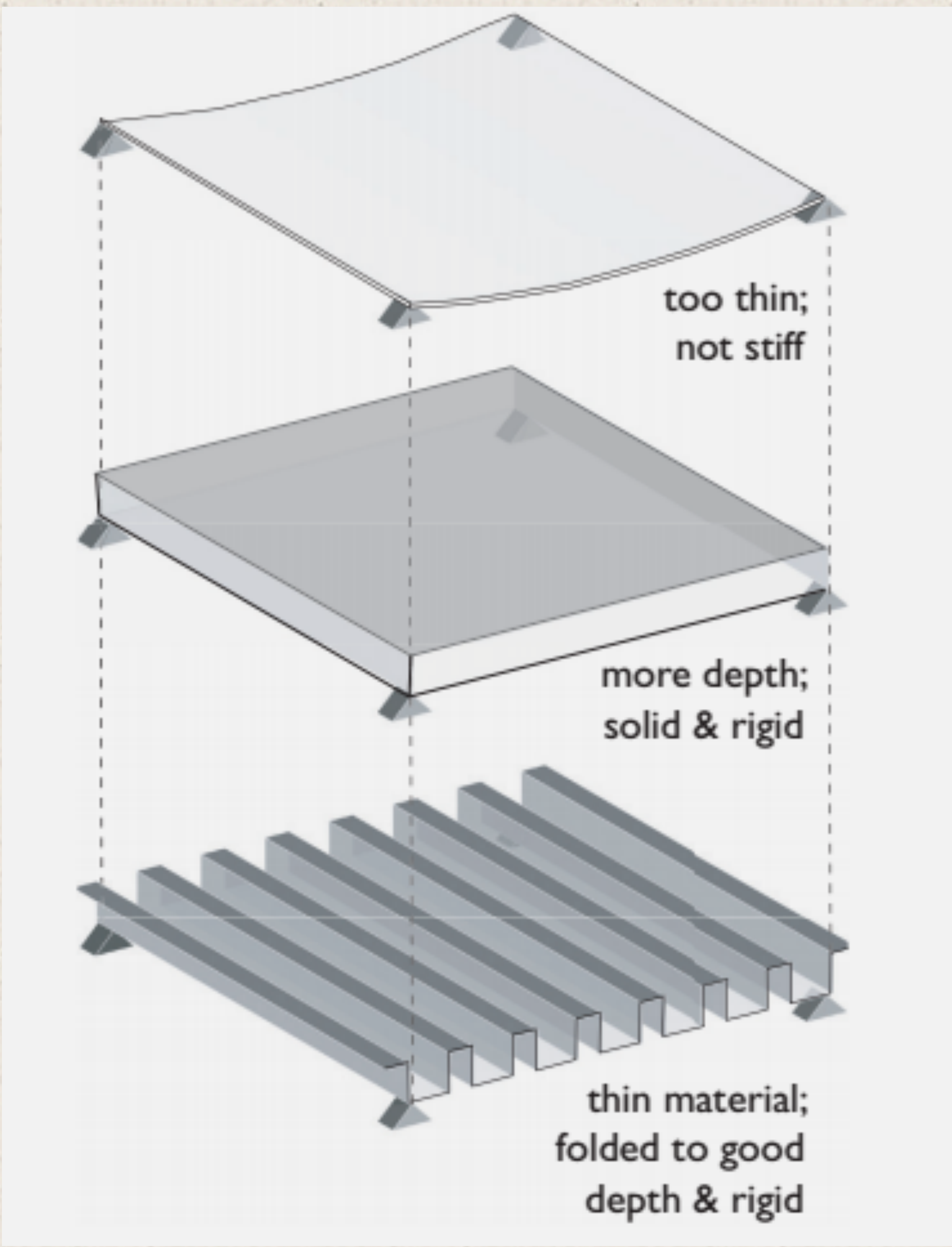
This is also why we reduce or eliminate materials near the center of the beam's cross-section, where stresses are lowest.

An I-beam or tube looks the way it does because its mass has been moved to its edges and its middle has been hollowed out as much as possible

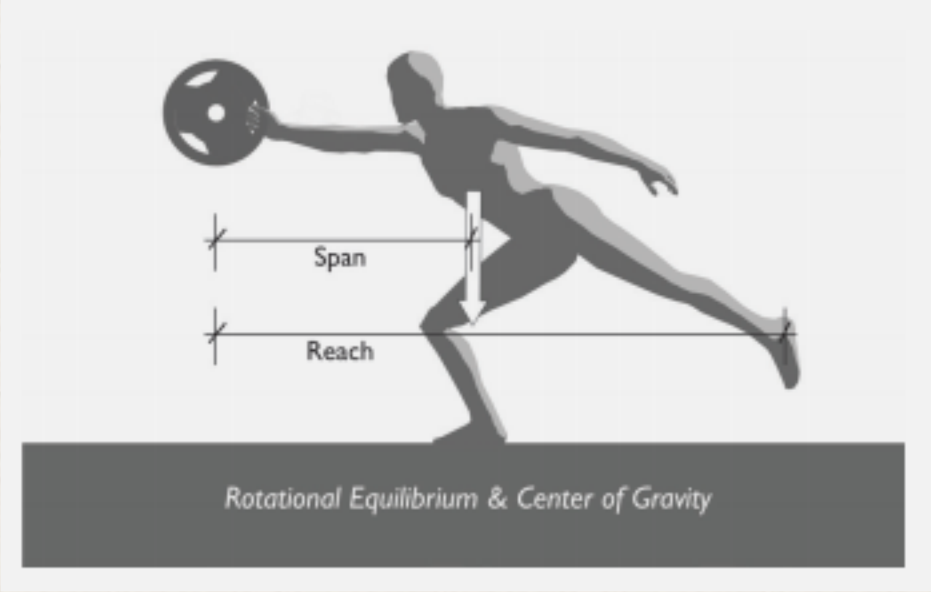


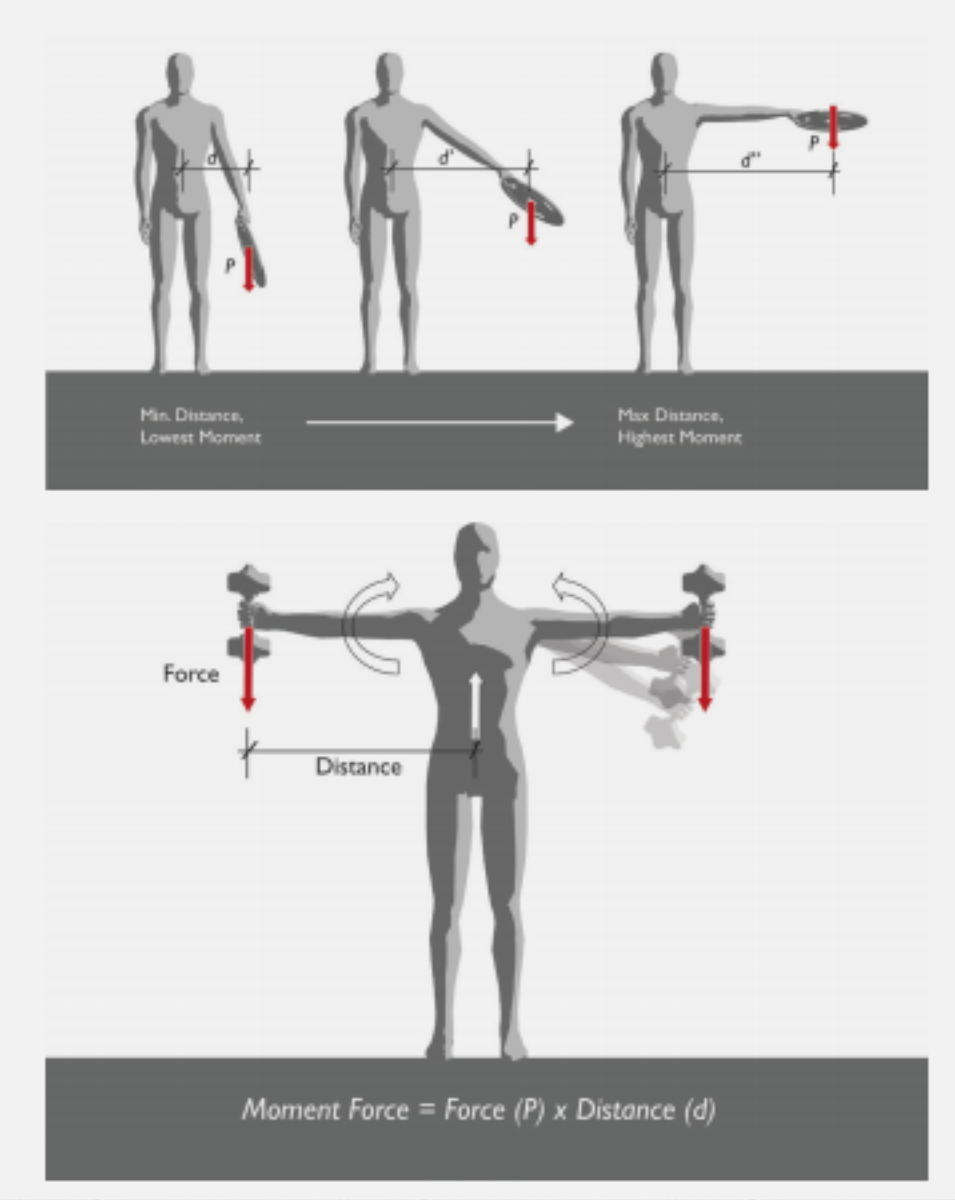
Plane of Bending
Load Causing Bending
Reaction
Neutral Axis of Cross Section
Compression
Tension
Bending Stress on Cross Section
Short Moment Arm; Requires Higher Forces to Resist Bending
Plane of Bending
Load Causing Bending
Reaction
Neutral Axis of Cross Section
Compression
Tension
Bending Stress on Cross Section
Long Moment Arm; Requires Lower Forces to Resist Bending



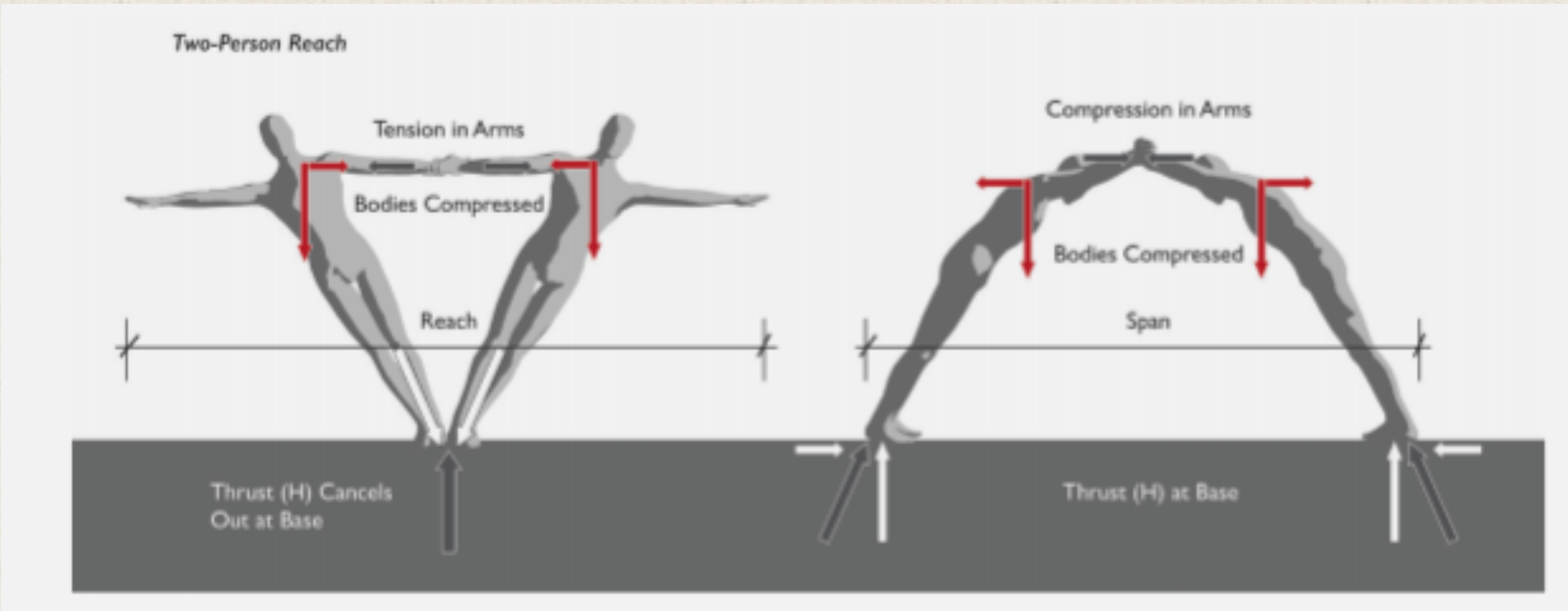

too thin;
not stiff
more depth;
solid & rigid
thin material;
folded to good
depth & rigid

Design Assignment: How Far Can You Span or Reach?





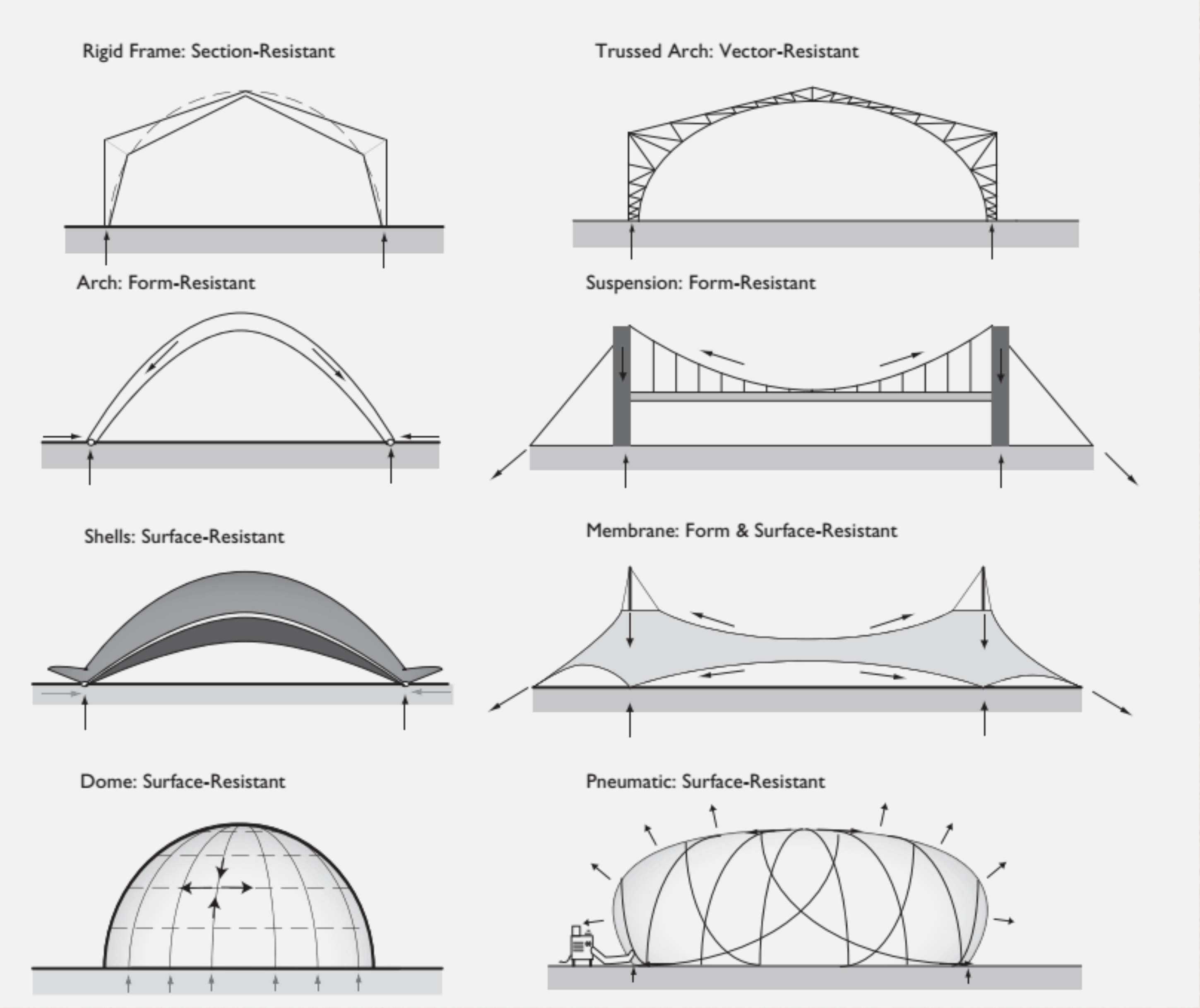
(d, known as a *moment arm*),


Two-Person Reach
Tension in Arms
Bodies Compressed
Reach
Thrust (H) Cancels
Out at Base
Compression in Arms
Bodies Compressed
Span
Thrust (H) at Base

Internal Stresses:
Form & Feeling
Tension in Body
Hanging Cable Form
Supports Lean Out
Bending in Body
Beam-Like Form
Vertical Supports

Internal Stresses:
Form & Feeling
Tension in Body
Hanging Cable Form
Supports Lean Out
Bending in Body
Beam-Like Form
Vertical Supports

Eero Saarinen's Washington Dulles Airport


Rigid Frame: Section-Resistant
Trussed Arch: Vector-Resistant
Arch: Form-Resistant
Suspension: Form-Resistant
Shells: Surface-Resistant
Membrane: Form & Surface-Resistant
Dome: Surface-Resistant
Pneumatic: Surface-Resistant

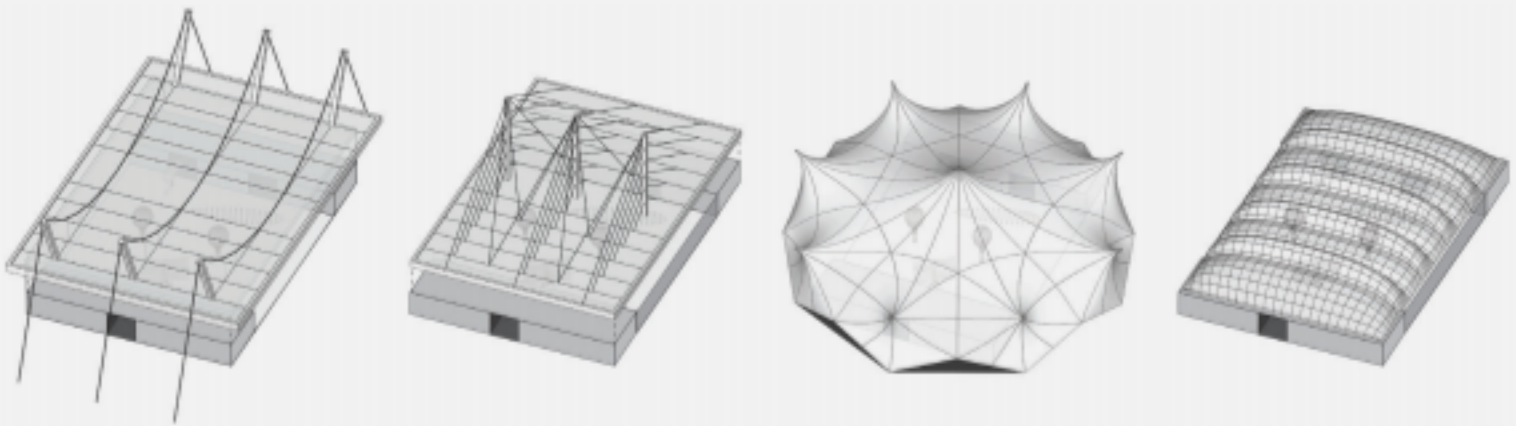


Figure 2.2.2 Four broad categories for tension systems (left to right): Suspended, cable-stayed, tent/membrane, and pneumatics

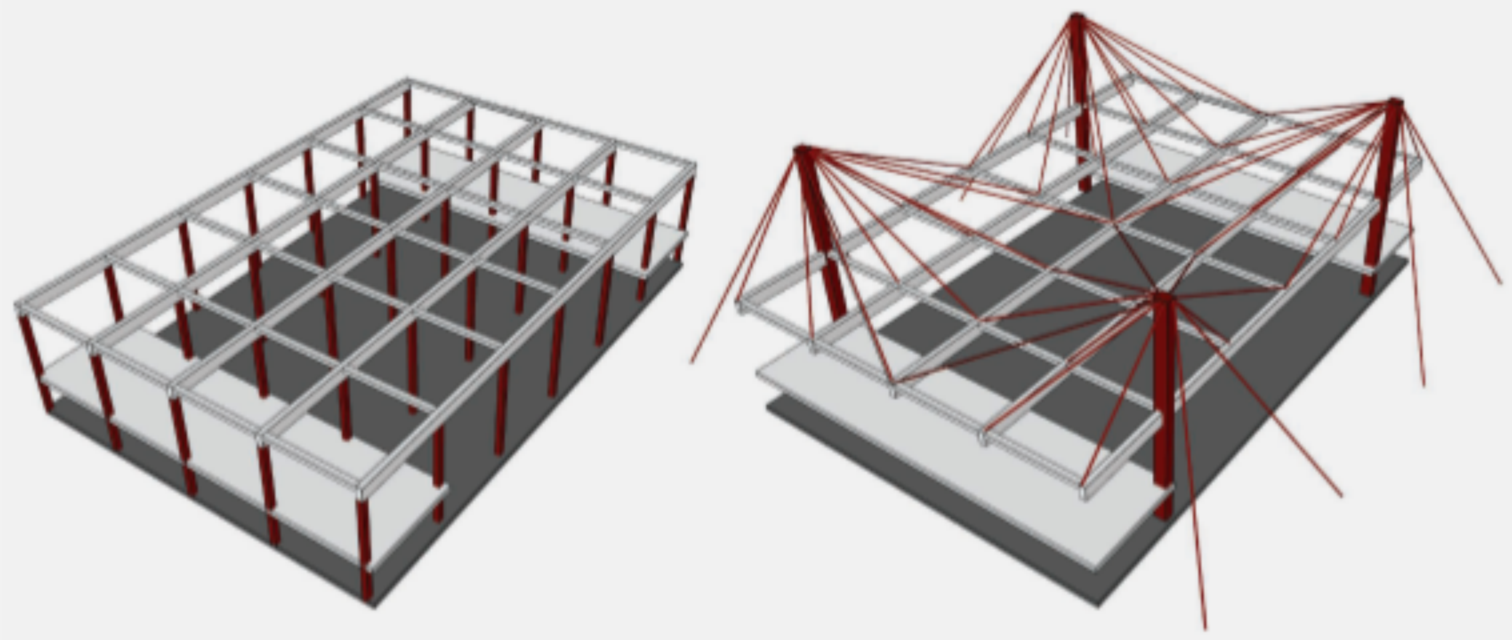
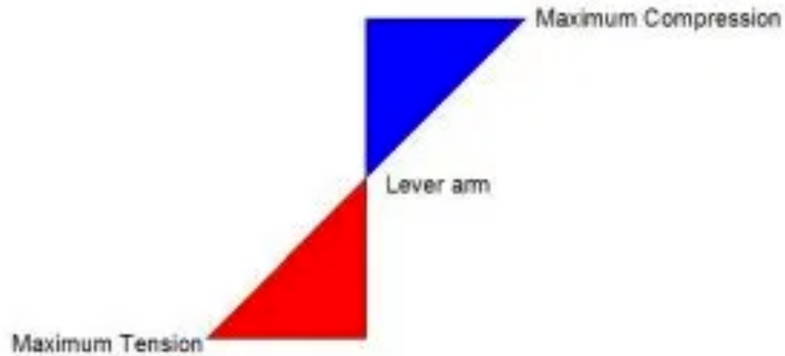


Figure 2.2.10 Comparing two options for vertical support: Columns or cable-stayed supports. Most columns can be eliminated if the cables pull the column loads up and concentrate them into fewer supporting masts

Maximum tension occurs at the bottom and dissipates linearly to the centre

Maximum compression occurs at the top and dissipates linearly to the centre

The diagram below shows what's happening to these forces:

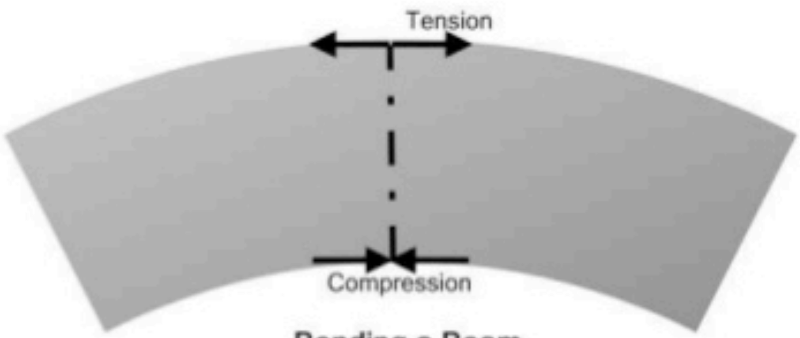


What we have here therefore is a Lever Arm "the tendency of a force to rotate an object about an axis"

This is a 'moment' diagram

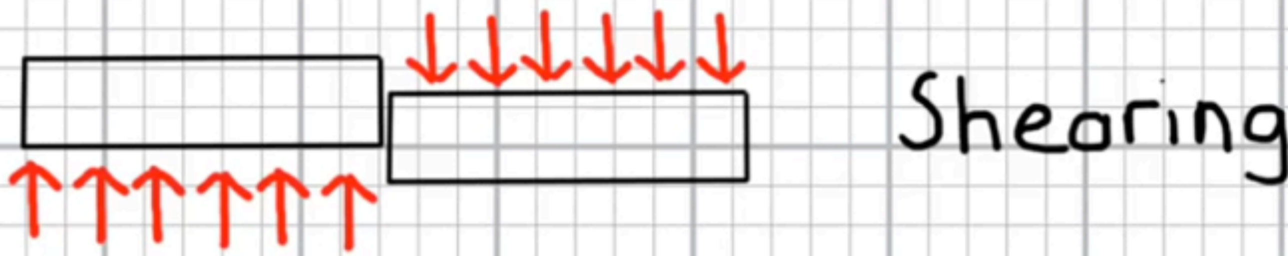
Definition of Bending Moment

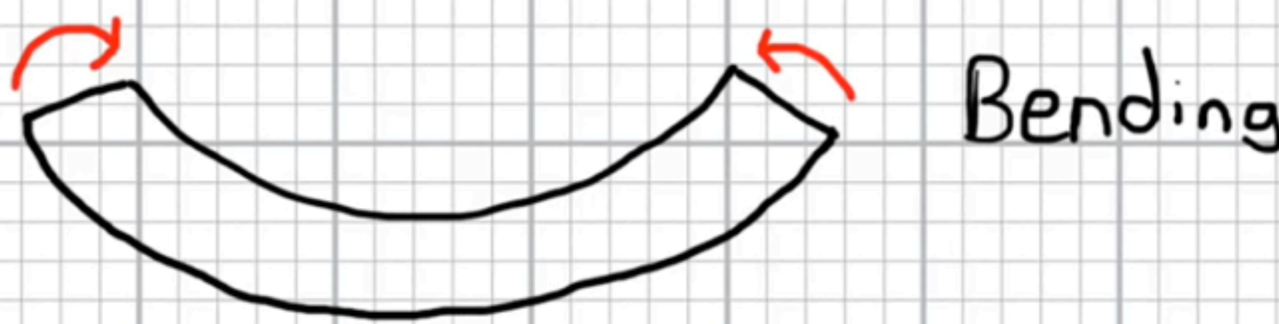
- A Bending Moment is the measure of the internal stress that produced by the external force or moment causing the element to bend.



Bending a Beam

Shear forces and bending moments:
The basics





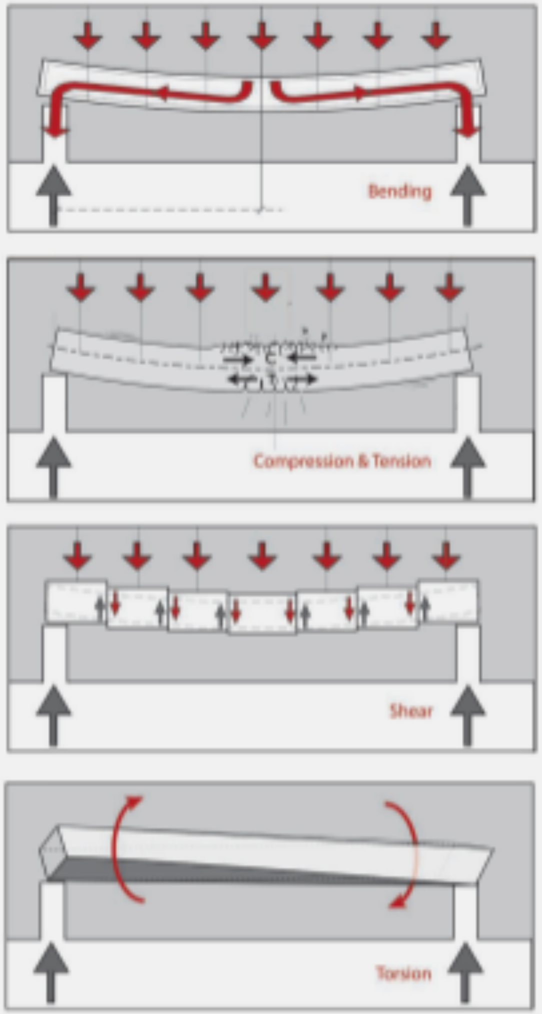


Figure 3.0.3 States of stresses in beams: Bending, compression, tension, shear, and torsion

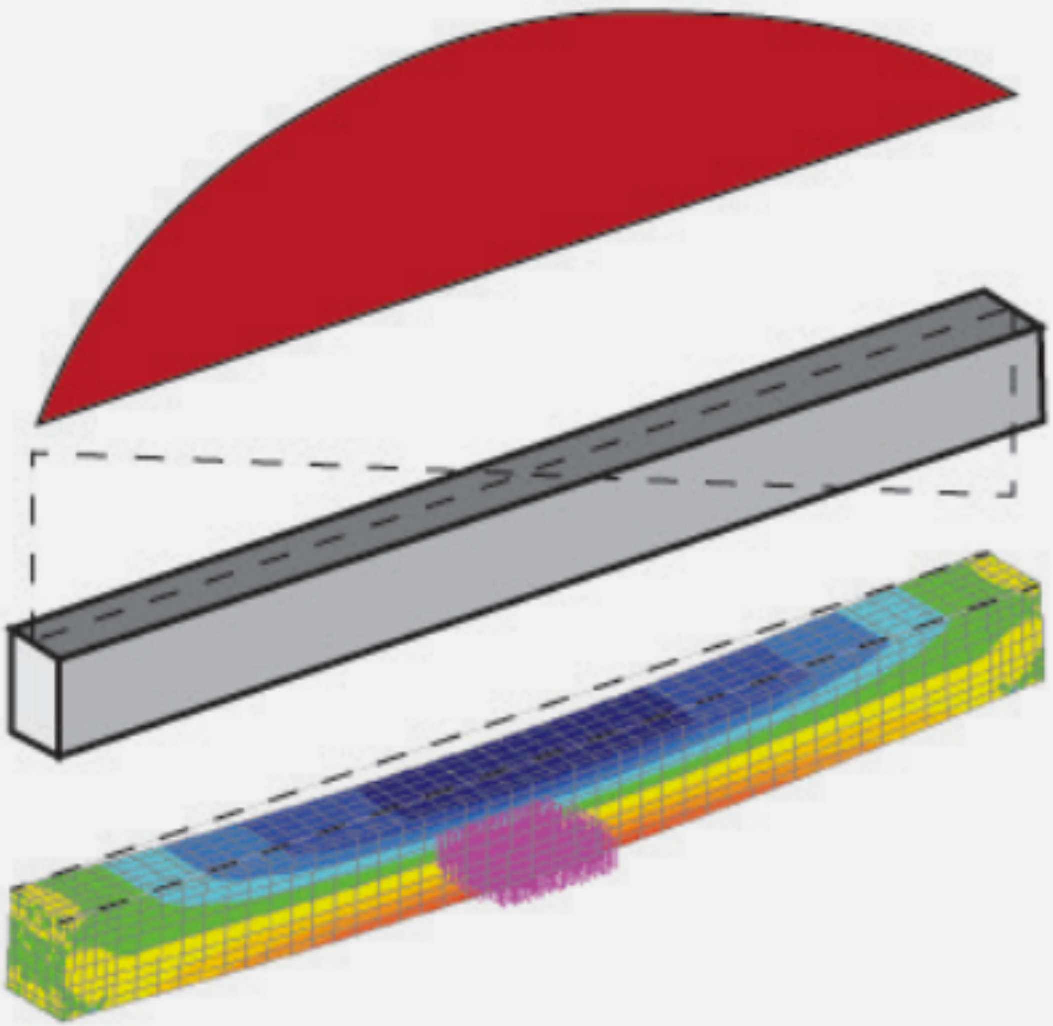
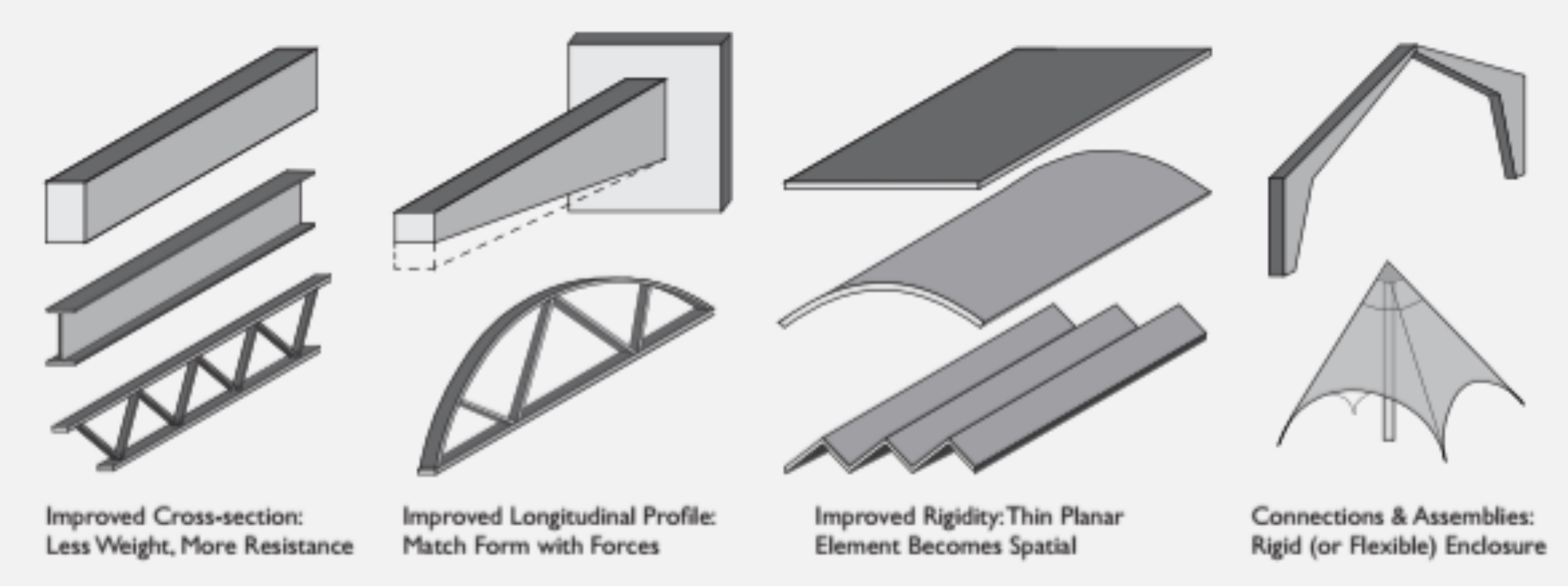
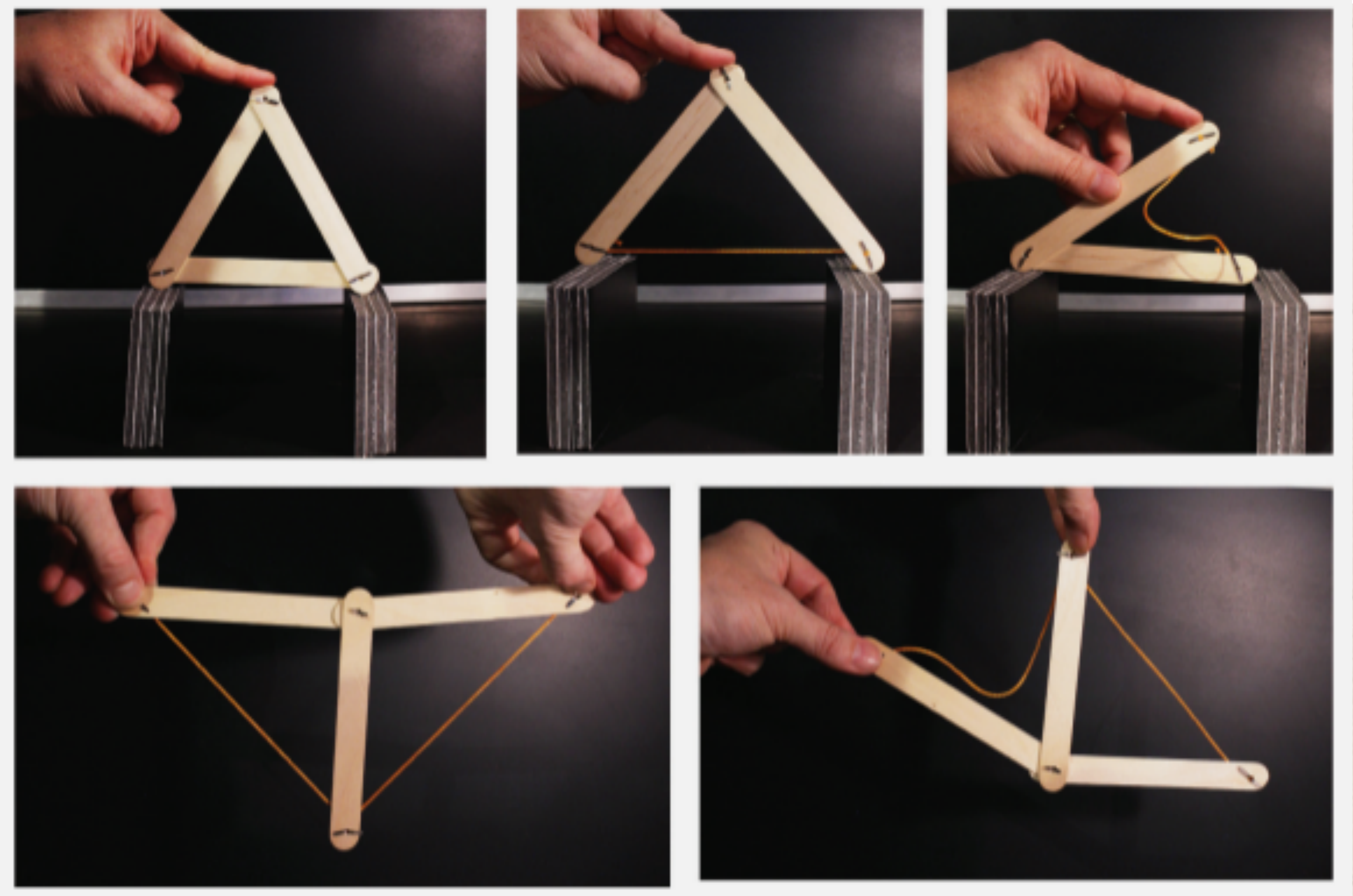
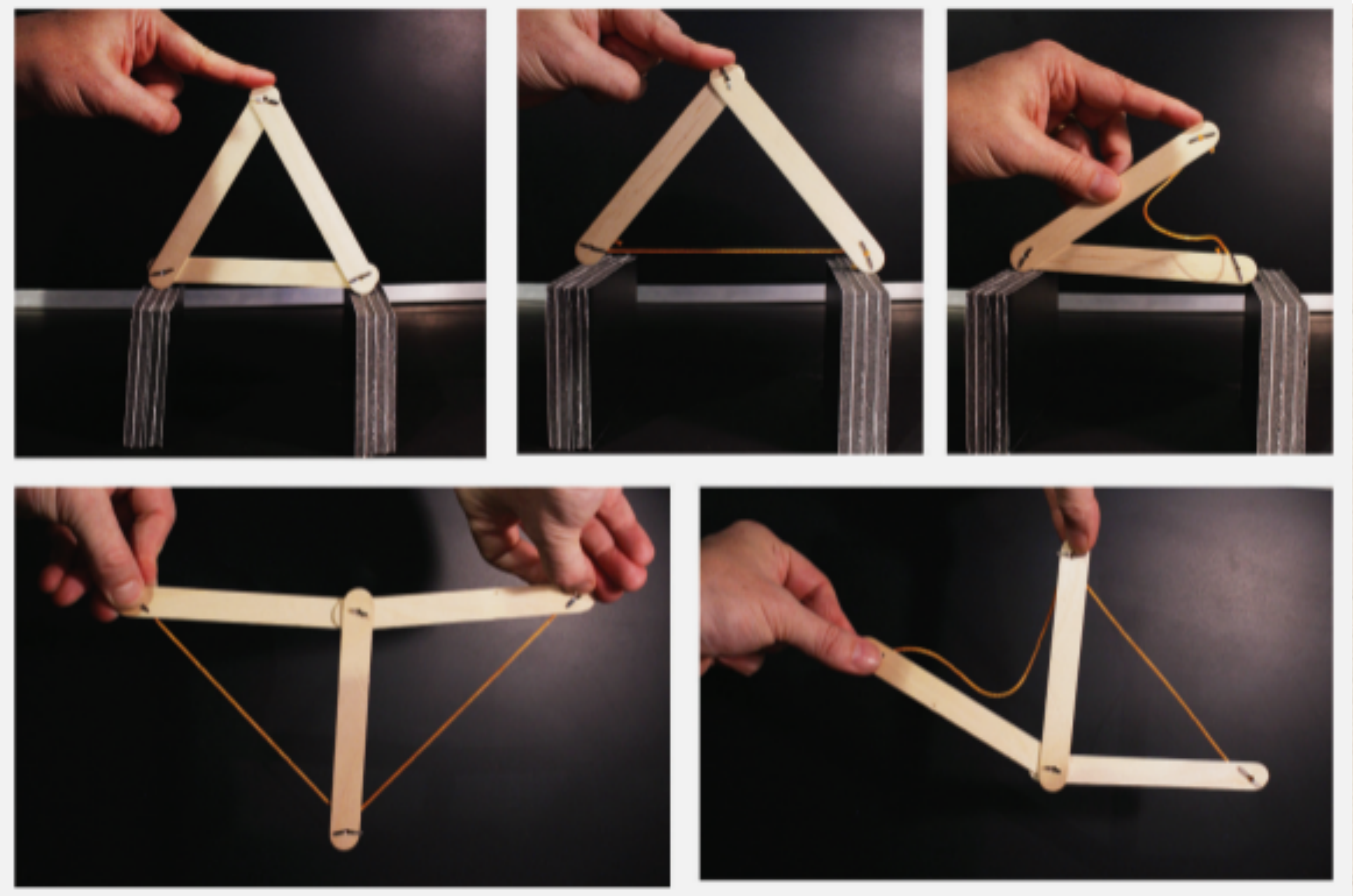


Figure 1.2.8 Determining locations of maximum stress and elongation under loading of a concrete beam using a moment diagram and a digital simulation

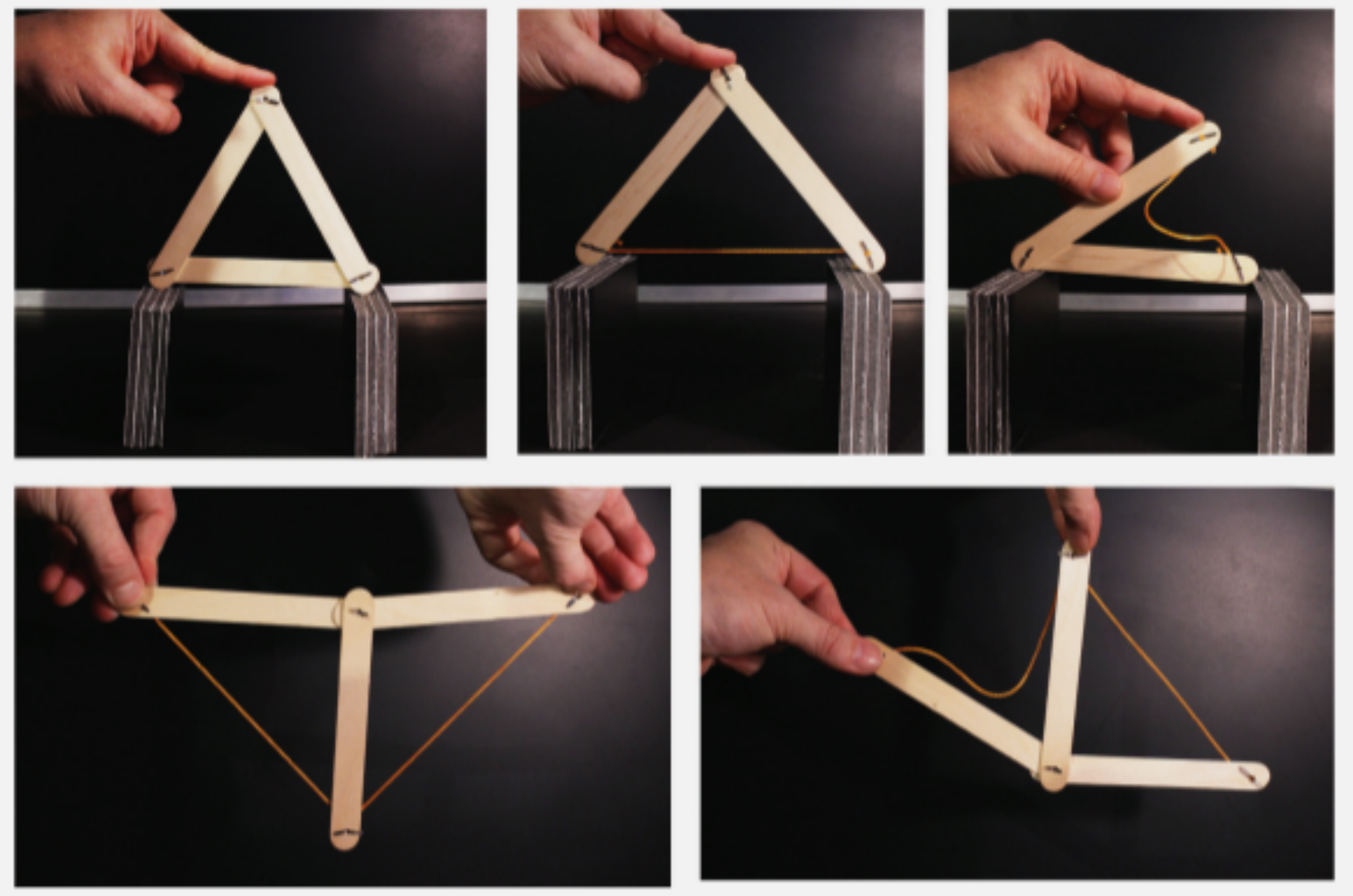

Improved Cross-section:
Less Weight, More Resistance
Improved Longitudinal Profile:
Match Form with Forces
Improved Rigidity: Thin Planar
Element Becomes Spatial
Connections & Assemblies:
Rigid (or Flexible) Enclosure



Place the string along the bottom and press down at the top point (watch the string tense). Now rotate it and press down again (watch the string sag under compression).



The A-framed components were resisting compression, like an arch, while the bottom component tied them together to resist thrust (tension)



Reorient the panel so the string is at the bottom (to resist tension) and link this panel with another similar panel at the base (share a node point).

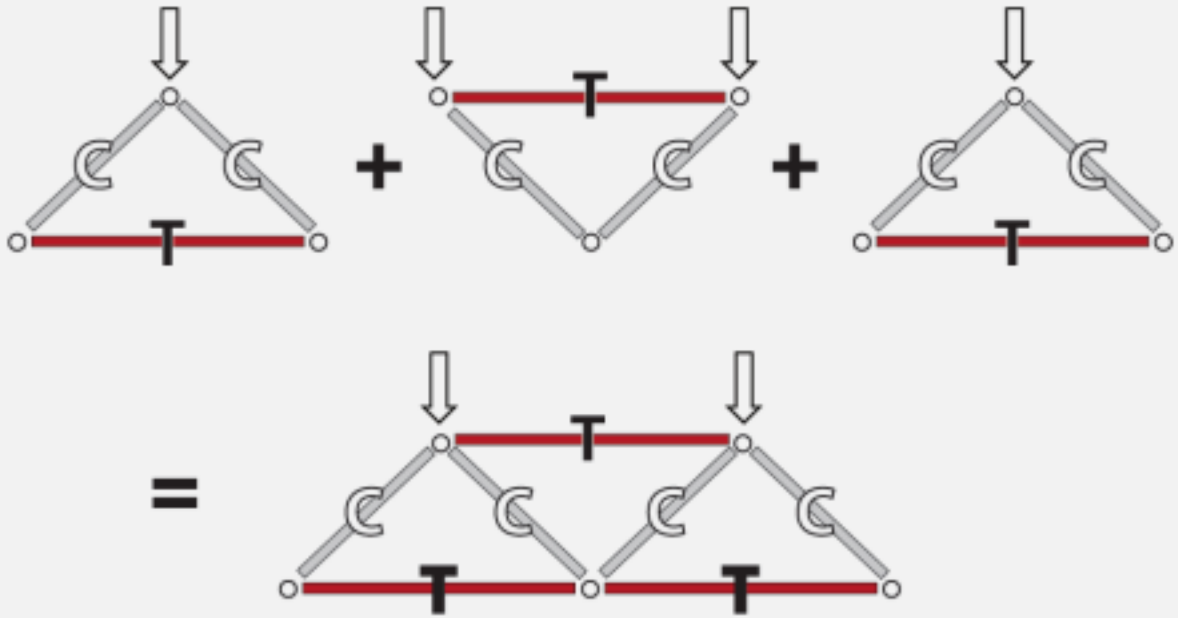


Figure 4.0.18 To understand which members are in compression versus tension, imagine the truss (in the internal stress) first as separate panels

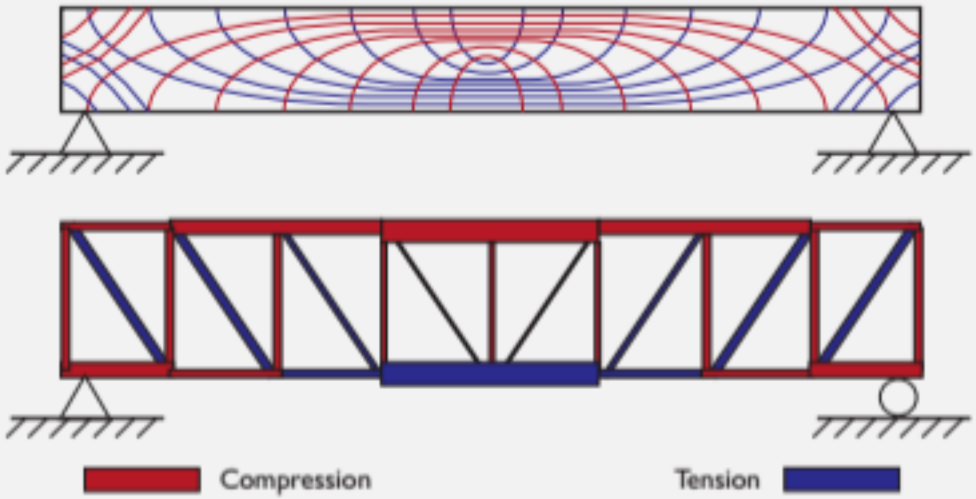
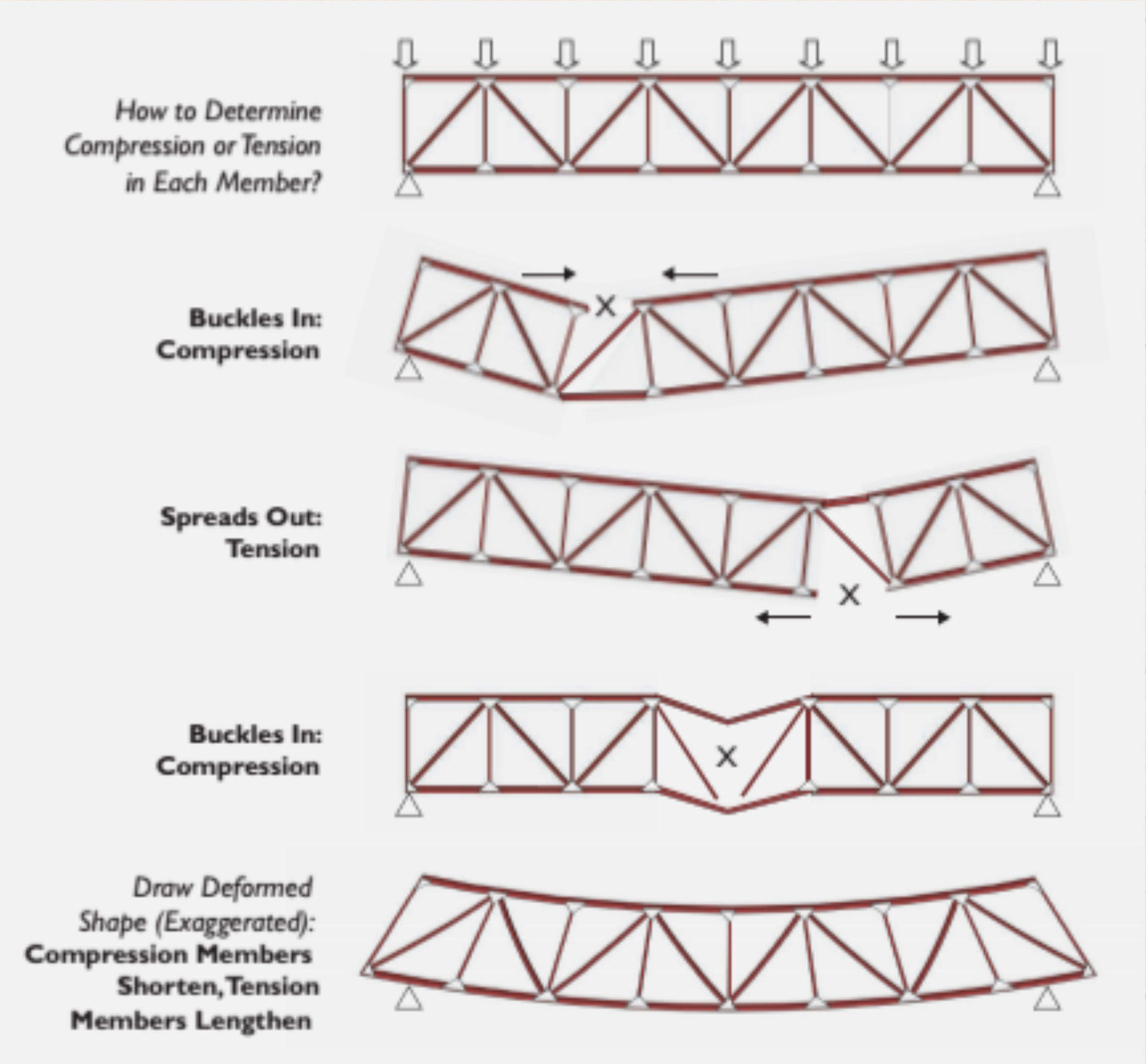
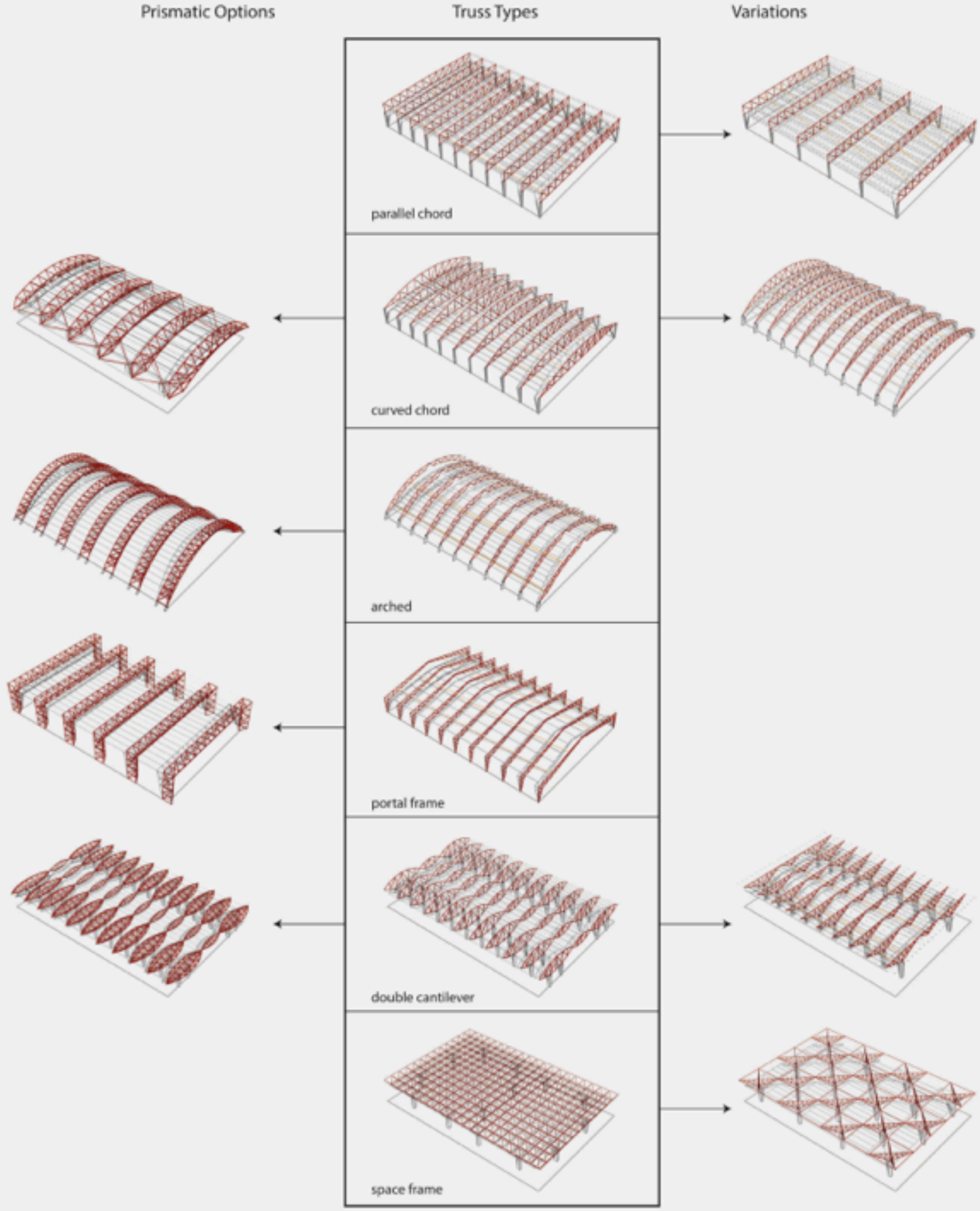


Figure 4.0.19 Internal force flow of a beam and stress distribution for a truss of same length. Location of compression and tension stresses and patterns of distribution across their lengths are similar


How to Determine Compression or Tension in Each Member?
Buckles In: Compression
X
Spreads Out: Tension
X
Buckles In: Compression
X
Draw Deformed Shape (Exaggerated): Compression Members Shorten, Tension Members Lengthen



Prismatic Options
Truss Types
Variations
parallel chord
curved chord
arched
portal frame
double cantilever
space frame

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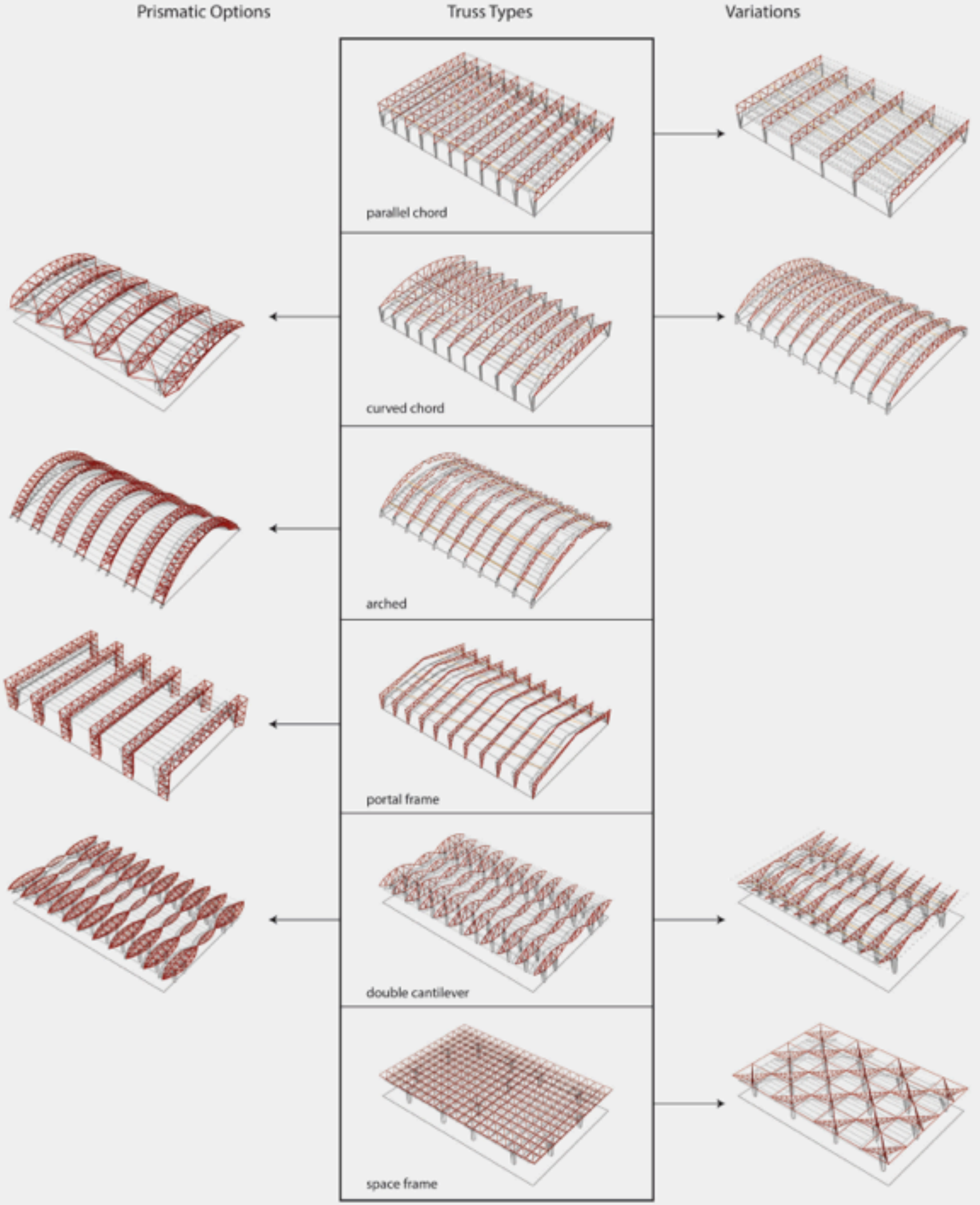


Figure 4.1.22 Hamburg Airport Terminal 2. Skylights above arched prismatic trusses with off-set columns (Architekten von Gerkan, Marg und Partner, 1993)

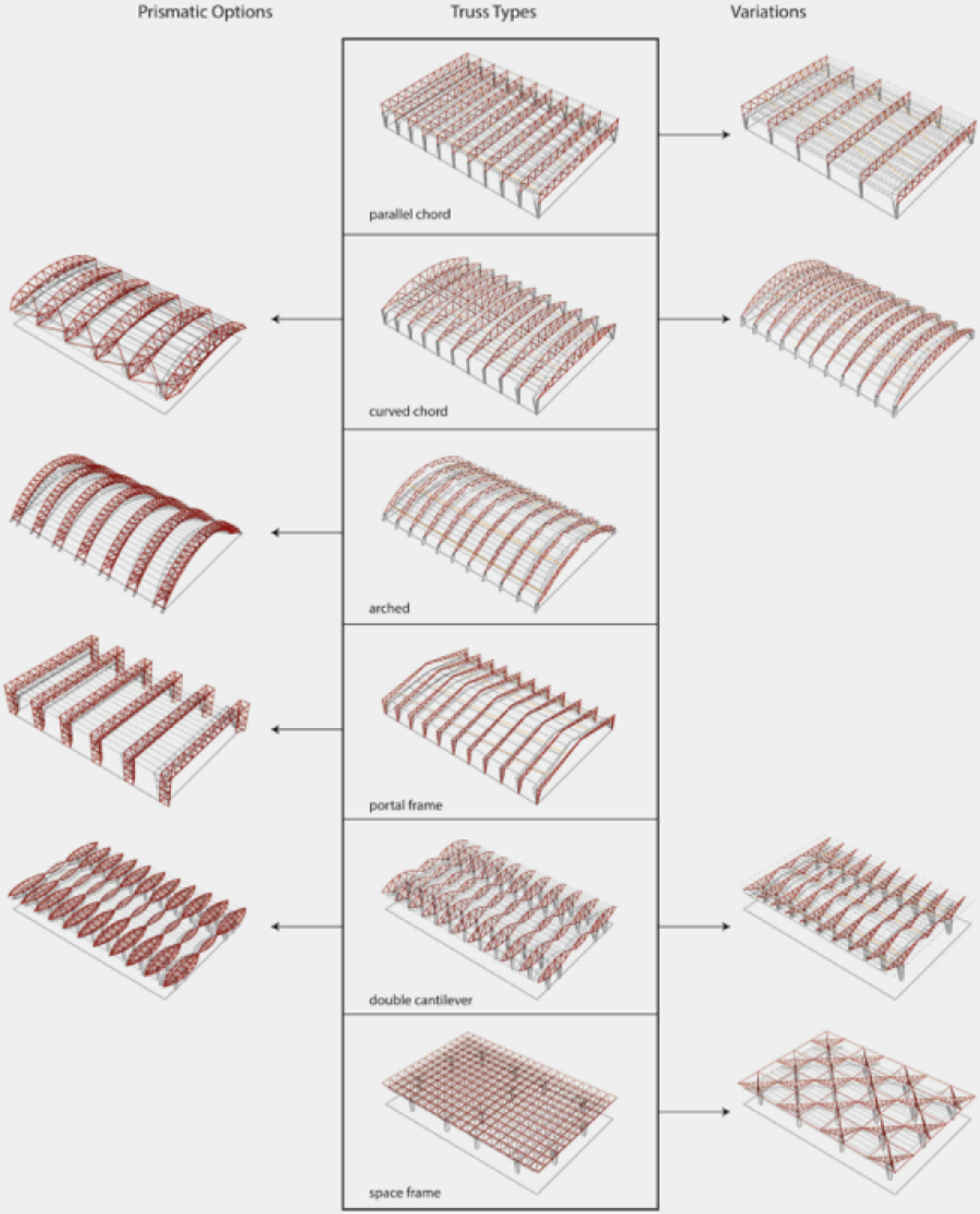
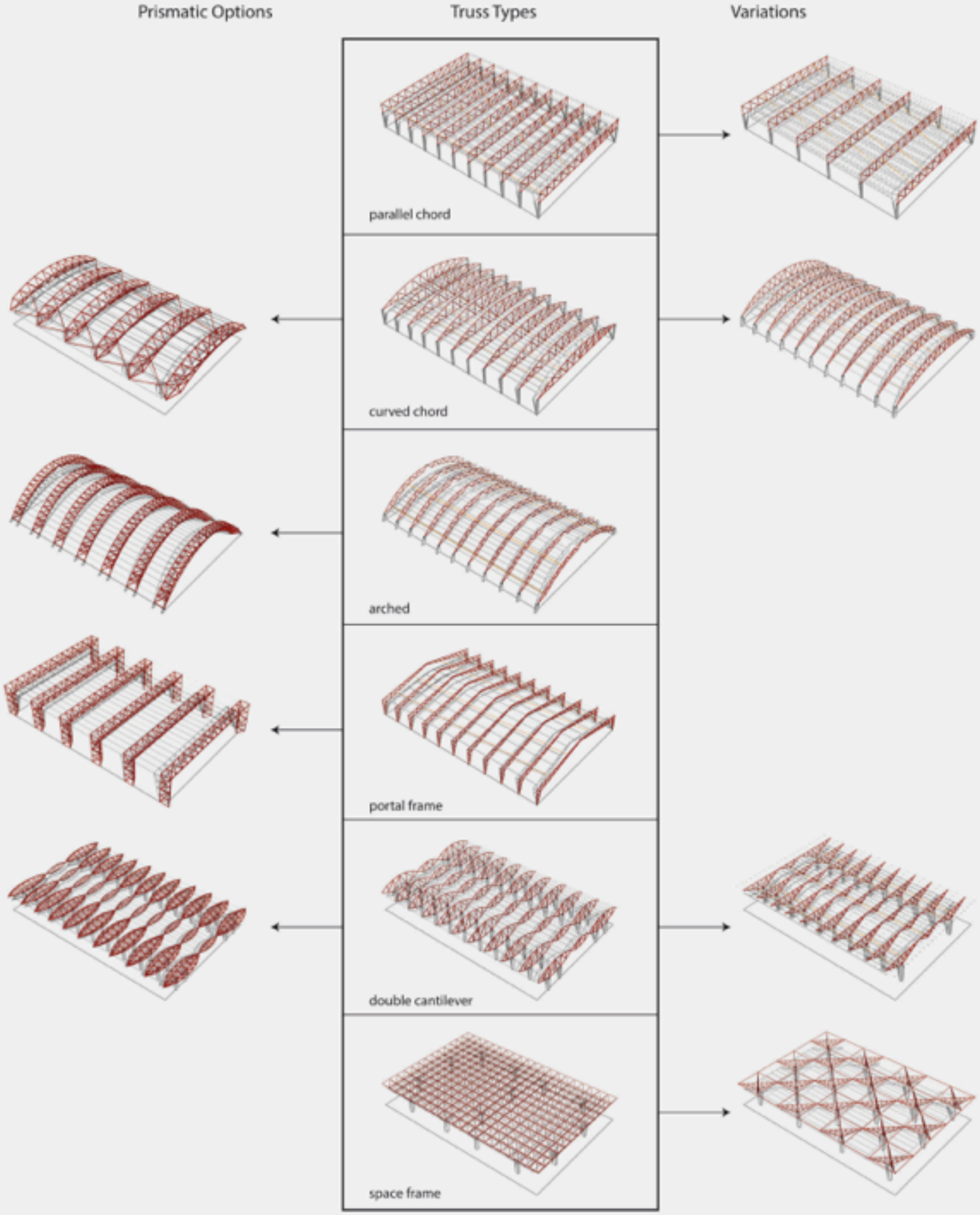


Figure 4.1.41 Construction framing of double-curved surface using space frame trusses at Heydar Aliyev Cultural Centre (Zaha Hadid Architects, Baku, 2012)



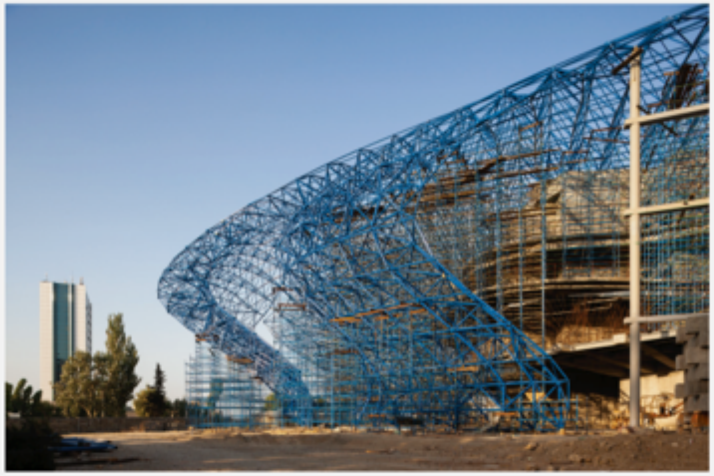


Figure 4.1.41 Construction framing of double-curved surface using space frame trusses at Heydar Aliyev Cultural Centre (Zaha Hadid Architects, Baku, 2012)

Glass Fibre Reinforced Concrete (GFRC) and Glass Fibre Reinforced Polyester (GFRP) were used as cladding

PROPERTIES OF TIMBER BUILDING MATERIALS (STRENGTH AND STIFFNESS)

Douglas Fir, Select:

Density:
0.0230 lbs/in3, 0.0006 kg/cm3

Allowable Bending (f'b):
1,450 lbs/in2, 102 kg/cm2

Allowable Shear (f'v):
100 lbs/in2, 7 kg/cm2

Modulus of Elasticity
1,900,000 lbs/in2, 133,589 kg/cm2

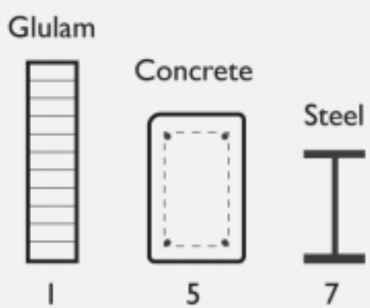
Southern Pine, Select:

Density:
0.0230 lbs/in3, 0.0006 kg/cm3

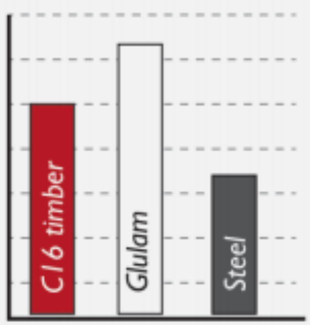
Allowable Bending (f'b):
2,000 lbs/in2, 141 kg/cm2

Allowable Shear (f'v):
128 lbs/in2, 9 kg/cm2

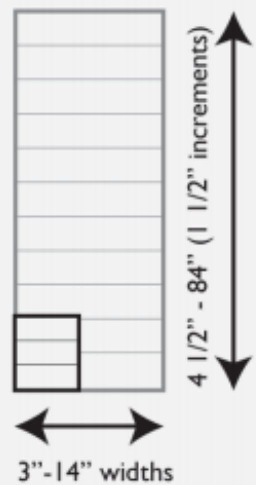
Modulus of Elasticity
1,600,000 lbs/in2, 112,500 kg/cm2



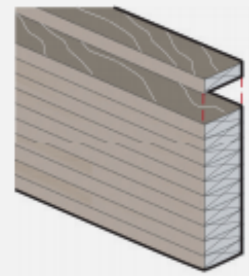
Energy units for equivalent beams based on materiality



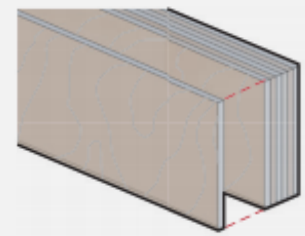
Strength-to-weight ratio



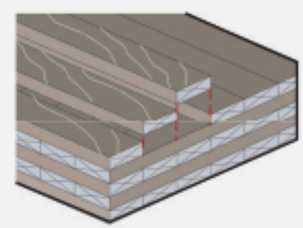
Range of Glulam sizes



Glue-Laminated Timber (Glulam):
-Beams & Columns
-Straight, Curved, & Custom Shapes
-Interior & Exterior



Structural Composites:
-Laminated Veneer (LVL), Parallel Strand (PSL), etc.
-Beams & Columns
-Straight members only
-Interior only



Cross-Laminated Timber (CLT):
-Floors, Walls, & Roofs
-Planar Elements but customizable openings
-Interior only

- Wood is the only primary building material that comes from a renewable resource
- Naturally cleans the air in its natural state.
- We use nearly 100% of harvest wood as product.
- Its manufacturing has the lowest embodied energy and the least air and water emissions
- Is reusable, recyclable, and biodegradable.
- Wood is a more effective insulator than steel, masonry, or concrete.
- And it is an affordable.

Although some wood construction can rely on wood-to-wood connections like dowels, or modest steel fasteners (bolts, screws, lags, etc.), these connections cannot handle high stresses.

As such, mass timber structures rely on steel splice plates and connectors to ensure elevated shear resistance.

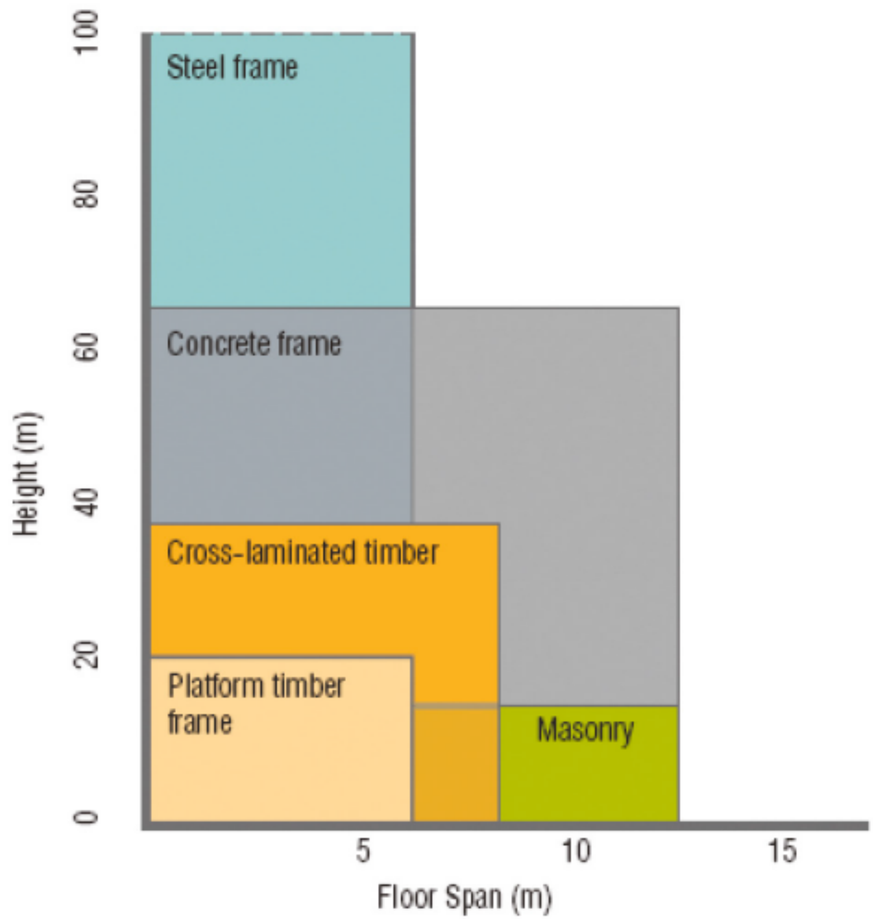


Figure 1

Span and height capabilities of mainstream structural materials in standard design.

Table 2: Approximate span and height capabilities of mainstream structural materials

Material	Floor span capability	Height capability
Steel frame	6–7m for composite steel/concrete floors	>100 storeys
Concrete frame	8–12m for solid, prestressed, troughed and ribbed slabs	>20 storeys
Platform timber frame	5–6m for engineered timber joists	7 storeys or 20m
CLT construction	6–8m	12 storeys or more possible*

* Design height limits above 12 storeys are subject to the engineering of the floors-to-walls interface design specific to the project.

CLT panels consist of not less than 3 cross-bonded layers of timber typically ranging in thickness between 20mm and 45mm.

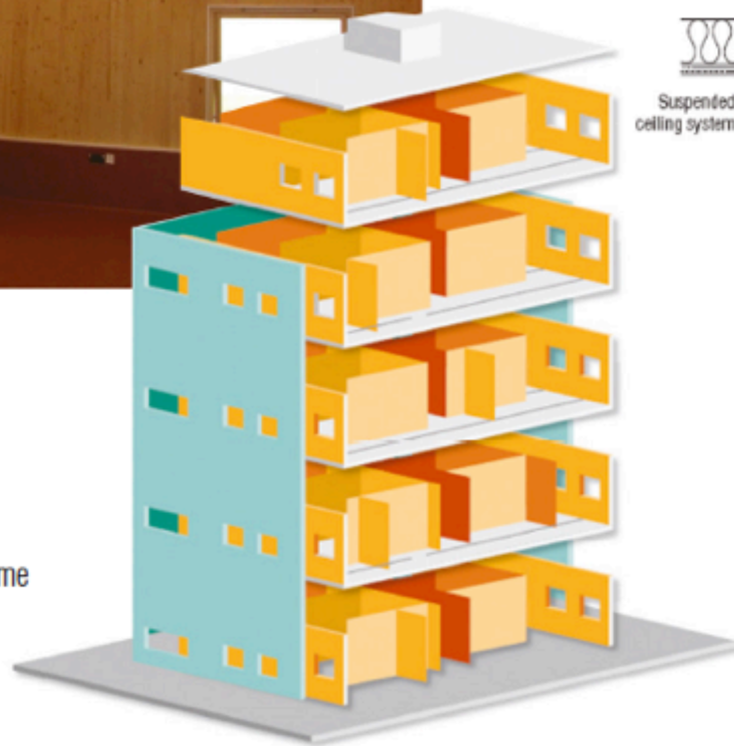
The timber is strength graded to BS EN 14081-1:2005 and glued together in a press, which applies pressure over the entire surface area of the panel.

CLT panels have an odd number of layers (3, 5, 7, 9) which may be of differing thicknesses;

layers are arranged symmetrically around the middle layer with adjacent layers having their grain direction at right angles to one another

Figure 2

CLT panel configuration



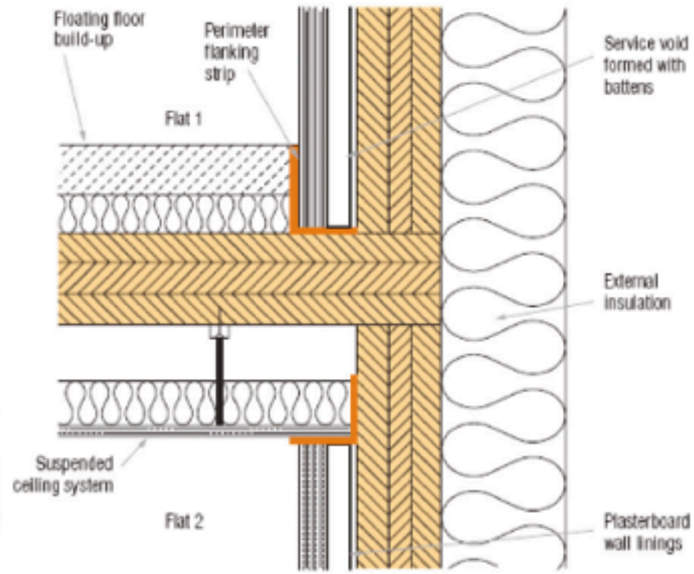


Figure 4

CLT roof panels formed as 'coupled' roof

Figure 5

Multistorey platform-frame construction using CLT

Figure 6

Typical CLT platform-frame external wall-floor junction

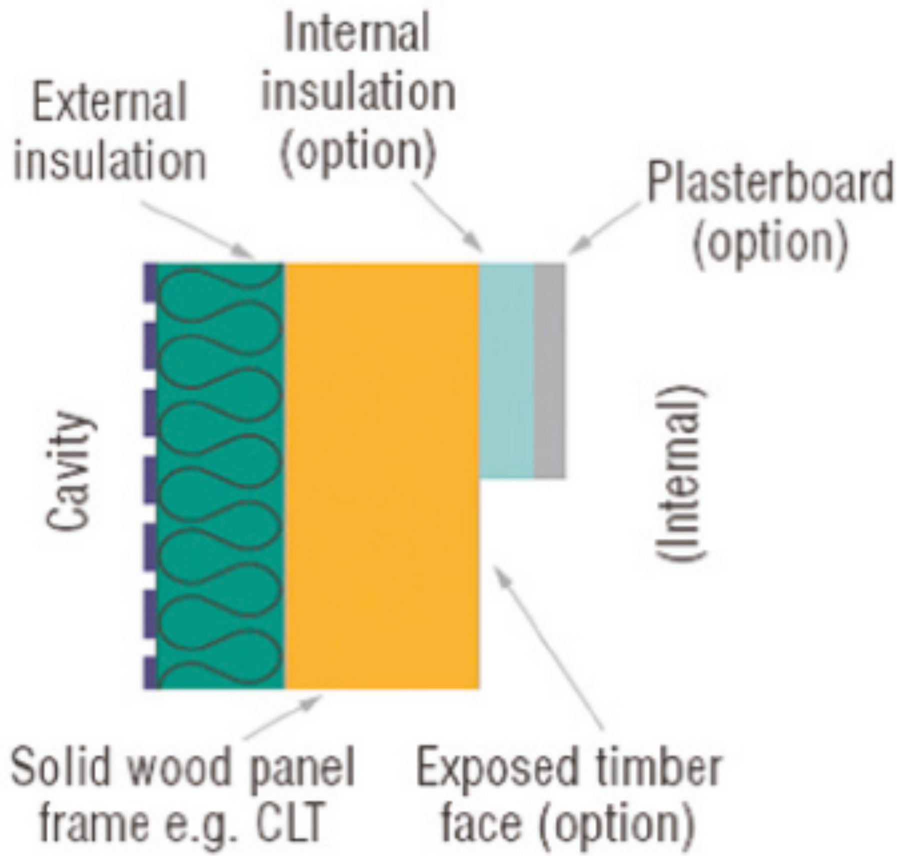


Figure 14

Typical build-up of CLT external wall construction

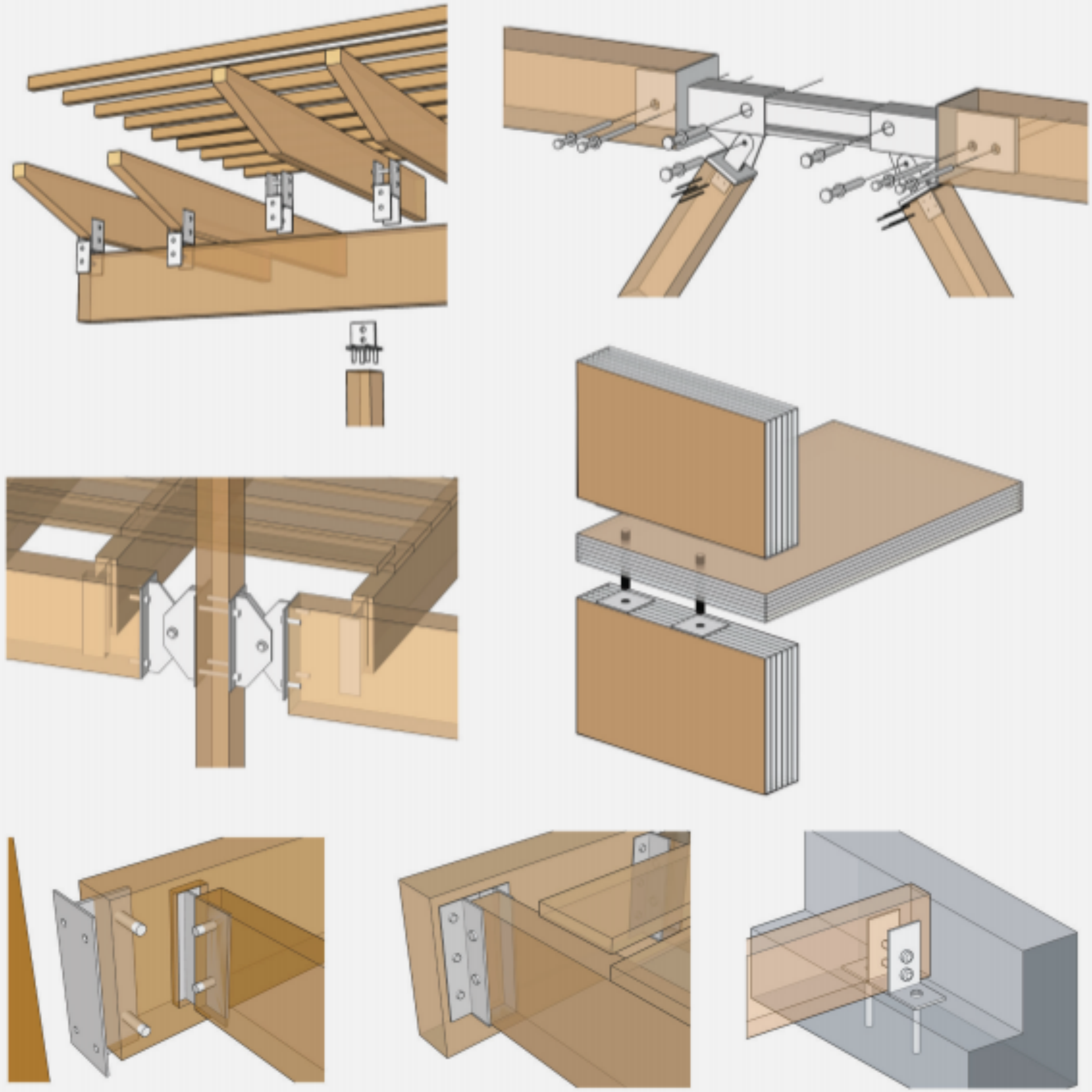


Figure 3.1.21 General details shown (left to right, top/down): Roof joist hangar, diagonal bracing bracket, pinned girder/column connection, CLT wall/floor (concealed), recessed (concealed) purlin/girder connection, exposed purlin/girder connection, and timber/concrete intersection

MAKING: MASS TIMBER DEVELOPMENTS

The benefits of heavy timber, improvements in their fabrication techniques, and changes in building codes, have made heavy timber construction a viable option for many mid-to-high rise buildings.

To Do: Find an example of a contemporary building that has recently been constructed using mass timber products—preferably multi-story. Collect information about the structural frame (including the structural bay sizes and the building sectional heights and depths). Find images of the construction process. Explain how the load collectors and load-grounding elements were combined to facilitate force flow.

To Discuss: How did the use of timber affect structural bay size, depths, and construction methods? What were the benefits of timber in these circumstances (structurally, aesthetically, environmentally, etc.). What were the liabilities or challenges? (Figure 3.1.17)

Figure 3.1.17 Mass timber (glulam and CLT) was used for the building frame, floors, walls, and trusses at the Olver Design Building at University of Massachusetts Amherst (Leers Weinzapfel Associates, 2017)