|||Shoots|||

Exploring bamboo
as a building/
design/construction/
engineering material

Hosted by A4A
20th-21st Oct 2007

www.a-4-a.org

Michael Gibbs

Rainforest Biome, Eden Project

Bamboo Biology and Species

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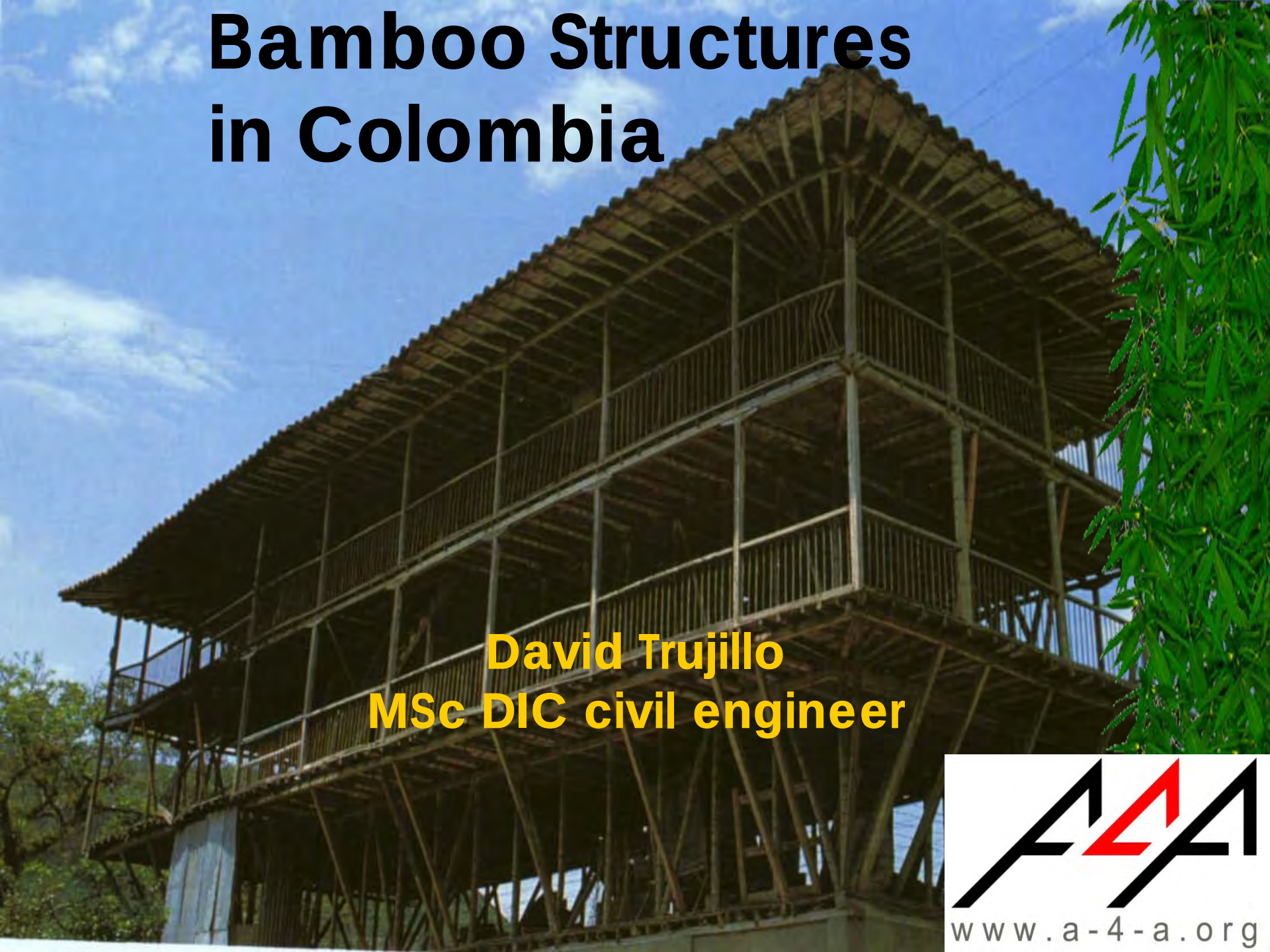
Bamboo Structures in Colombia



David Trujillo
MSc DIC civil engineer

www.a-4-a.org

What is Bamboo?

Buro Happold

What is Bamboo?

- **It is a giant grass – part of the *Gramineae* family .**
- **1100 species in the world, 451 in the Americas**
- **Large group of woody bamboos**
  - **141 species in Brazil**
  - **72 in Colombia**
- **11 million Ha of Latin America**

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What is *Guadua* bamboo?

- **Guadua genus contains 30 species**
- **Species of greatest structural applicability in Colombia: Guadua angustifolia Kunth**

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Guadua angustifolia Kunth

Where does *Guadua* bamboo grow?

- Native to Colombia, Ecuador and Venezuela
- Introduced to Costa Rica, Mexico, Puerto Rico, Brazil…

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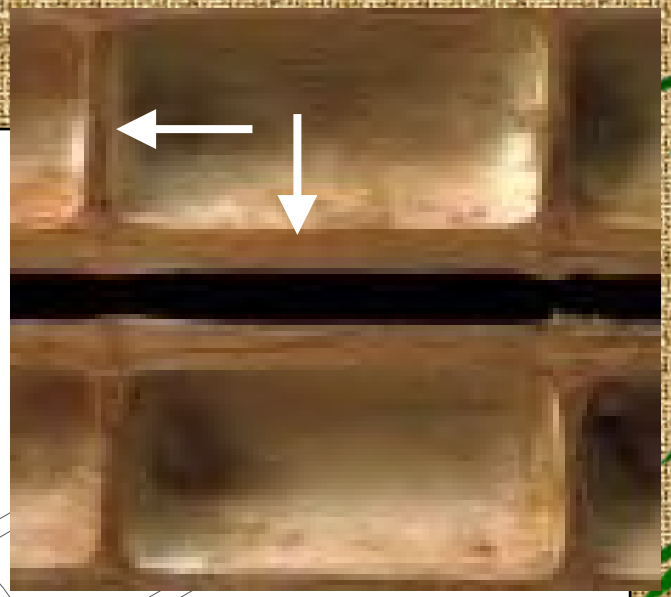
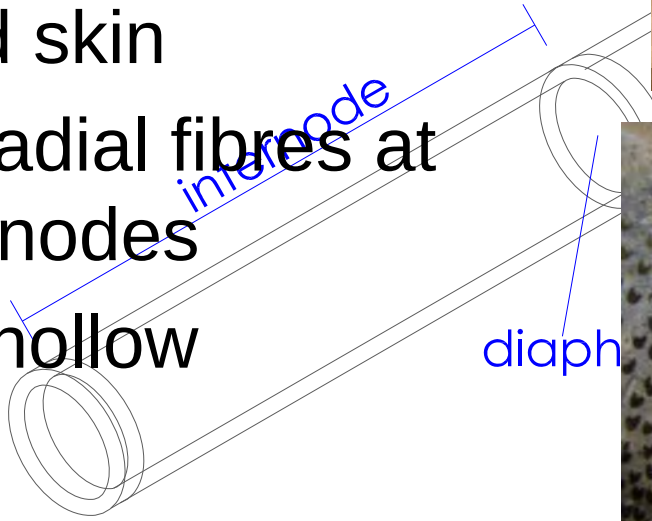
Anatomy of Bamboo

- Nodes and internodes
- No cambium
- No bark
- Hard skin
- No radial fibres at internodes
- It is hollow





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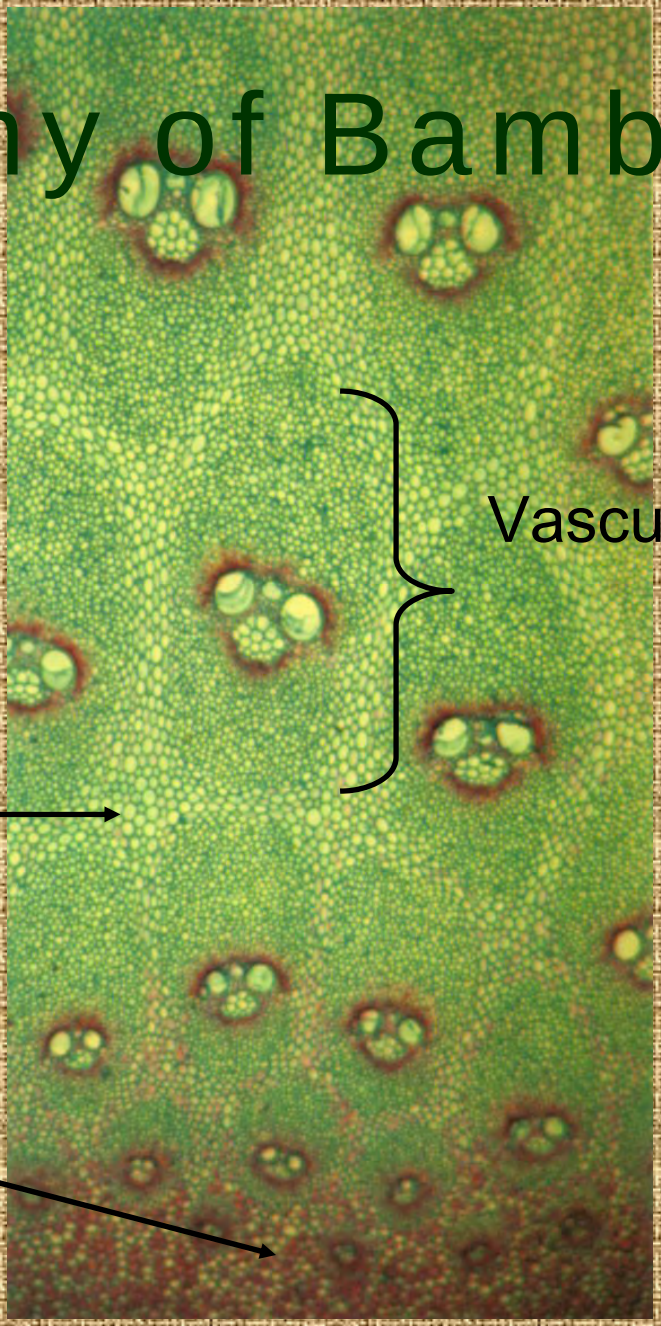
Anatomy of Bamboo

- Vascular bundles contain phloem, xylem and fibres.



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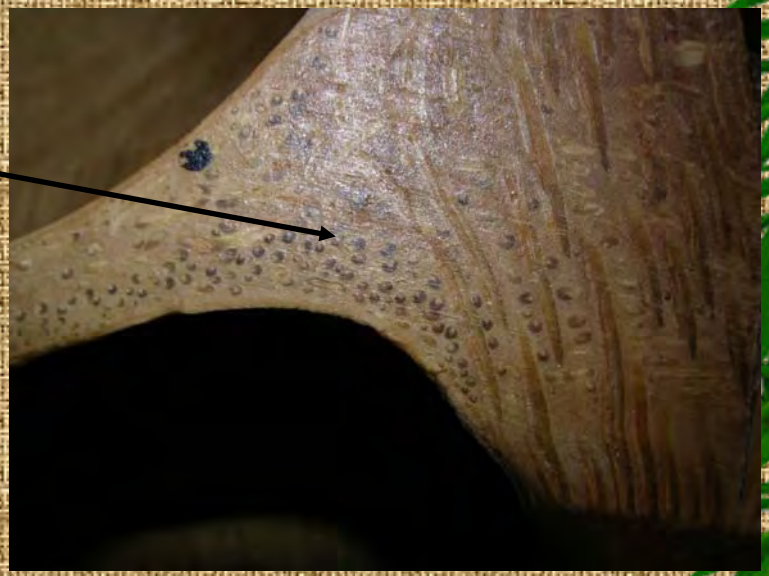
Anatomy of Bamboo

- Vascular bundles at nodes
- Vascular bundles at internodes



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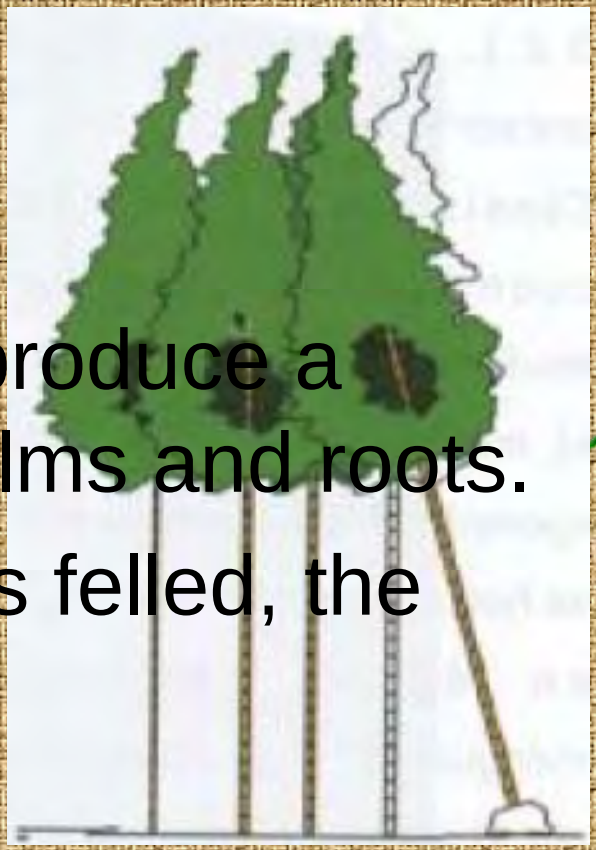
Life Cycle of Bamboo

- 20 – 25m in 6 months
- 3-5 years to mature
- Roots “branch-off” to produce a network of stems or culms and roots.
- When a stem or culm is felled, the clump still survives.
- Very sustainable.



Continue to Mechanical Properties

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Mechanical properties

(for Guadua angustifolia Kunth)

- Compression Parallel to grain
- $f_{c.0,k} = 28N/mm^2$
- C16 softwood
- $f_{c.0,k} = 17N/mm^2$

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Mechanical properties

(for Guadua angustifolia Kunth)

- Tension Parallel to grain
- $f_{t,0,k} = 90 N/mm^2$
- C16 softwood
- $f_{t,0,k} = 10 N/mm^2$

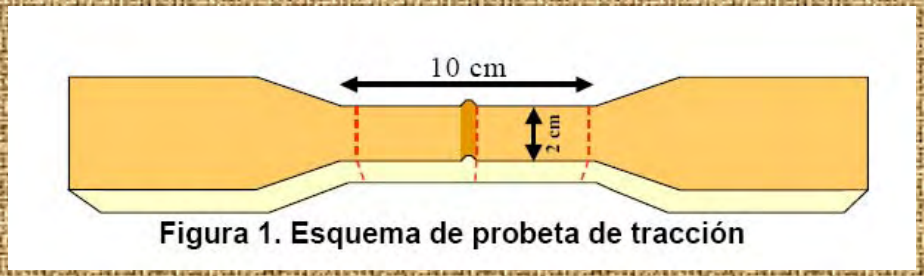

Figura 1. Esquema de probeta de tracción

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Mechanical properties

(for Guadua angustifolia Kunth)

- Bending
- $f_{m,k}$ = 46N/mm^2
- C16 softwood
- $f_{m,k}$ = 16N/mm^2

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Mechanical properties

(for Guadua angustifolia Kunth)

- Shear
- $f_{v,k} = 4\text{-}5 N/mm^2$
- C16 softwood
- $f_{v,k} = 1.8 N/mm^2$

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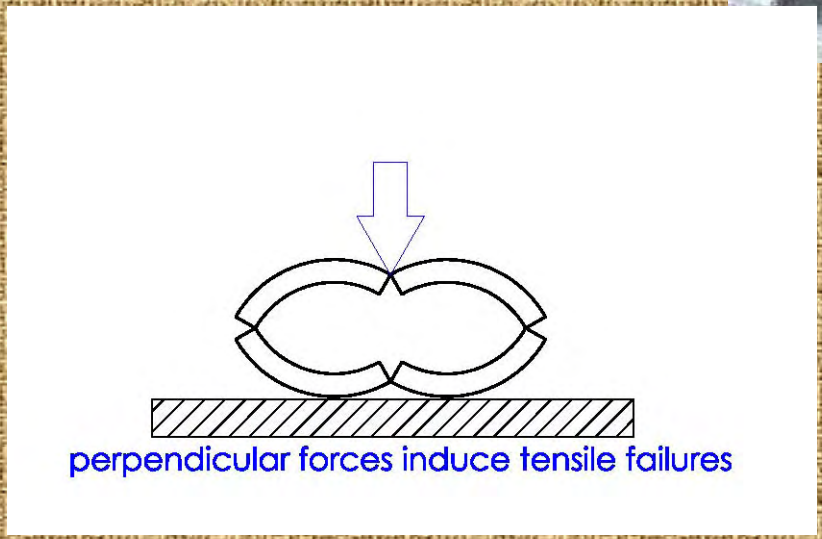
Mechanical properties

(for Guadua angustifolia Kunth)

- Compression perpendicular to grain
- $f_{c,90,k} = ?$



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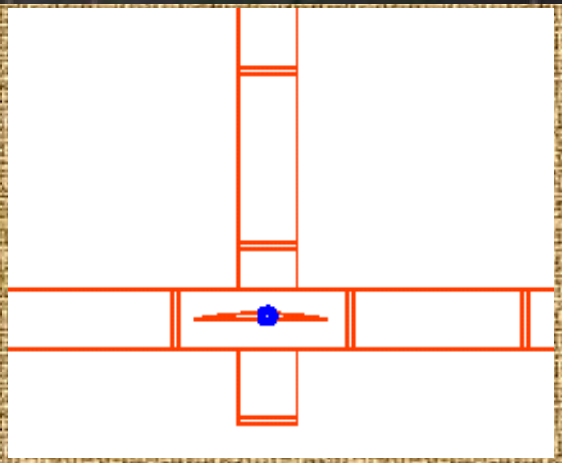
Mechanical properties

(for Guadua angustifolia Kunth)

- Tension Perpendicular to grain
- $f_{t,90,k} = 0.1 N/mm^2$
- C16 softwood
- $f_{t,90,k} = 0.3 N/mm^2$



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Moduli of elasticity

- Modulus of elasticity in compression
- $E_{c,0,mean} = 15000\ N/mm^2$
- Modulus of elasticity in bending
- $E_{m,mean} = 11800\ N/mm^2$
- C16 softwood
- $E_{mean} = 8800\ N/mm^2$

To history of bamboo use

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History of Bamboo use in Colombia

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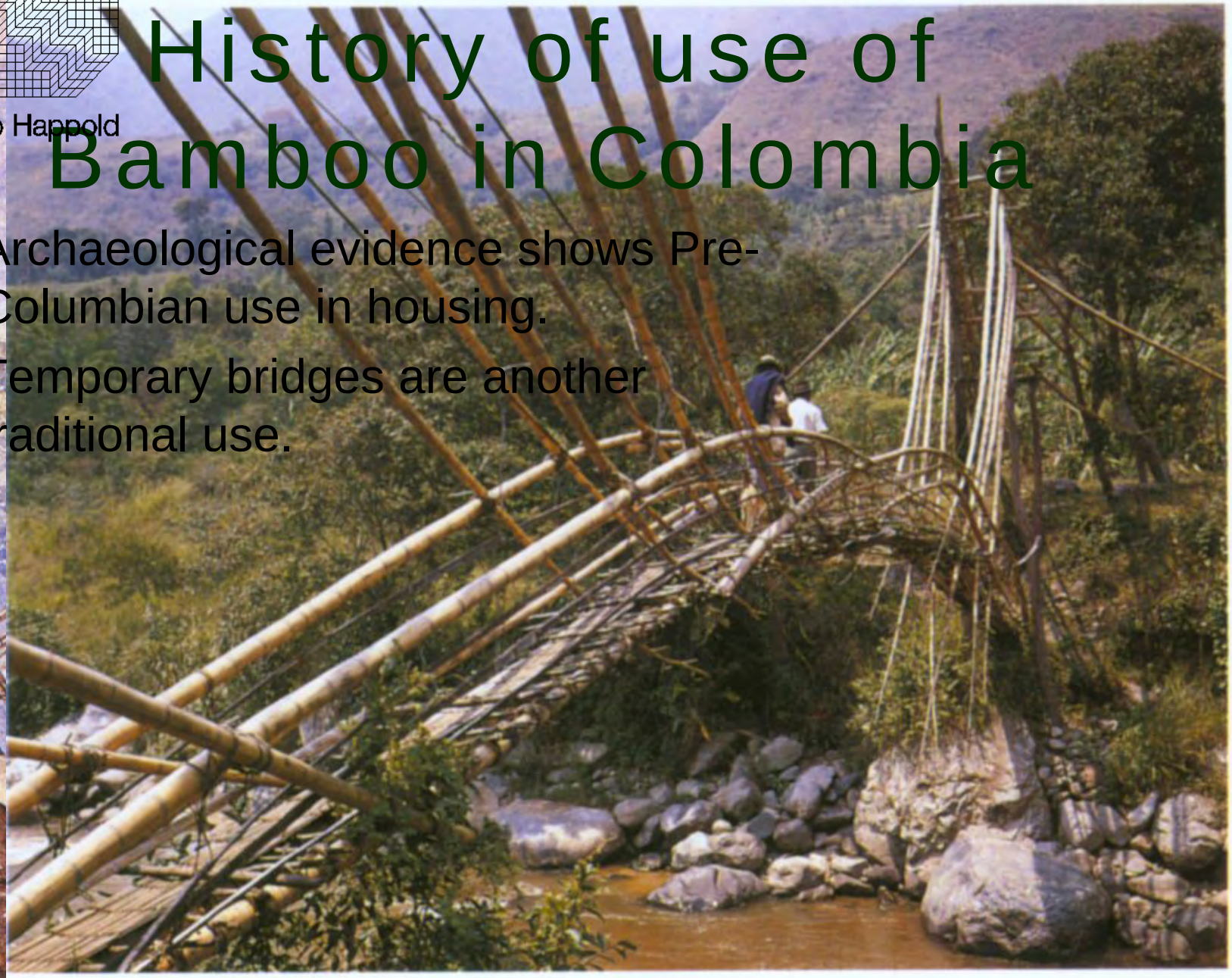
History of use of Bamboo in Colombia

- Archaeological evidence shows Pre-Columbian use in housing.
- Temporary bridges are another traditional use.



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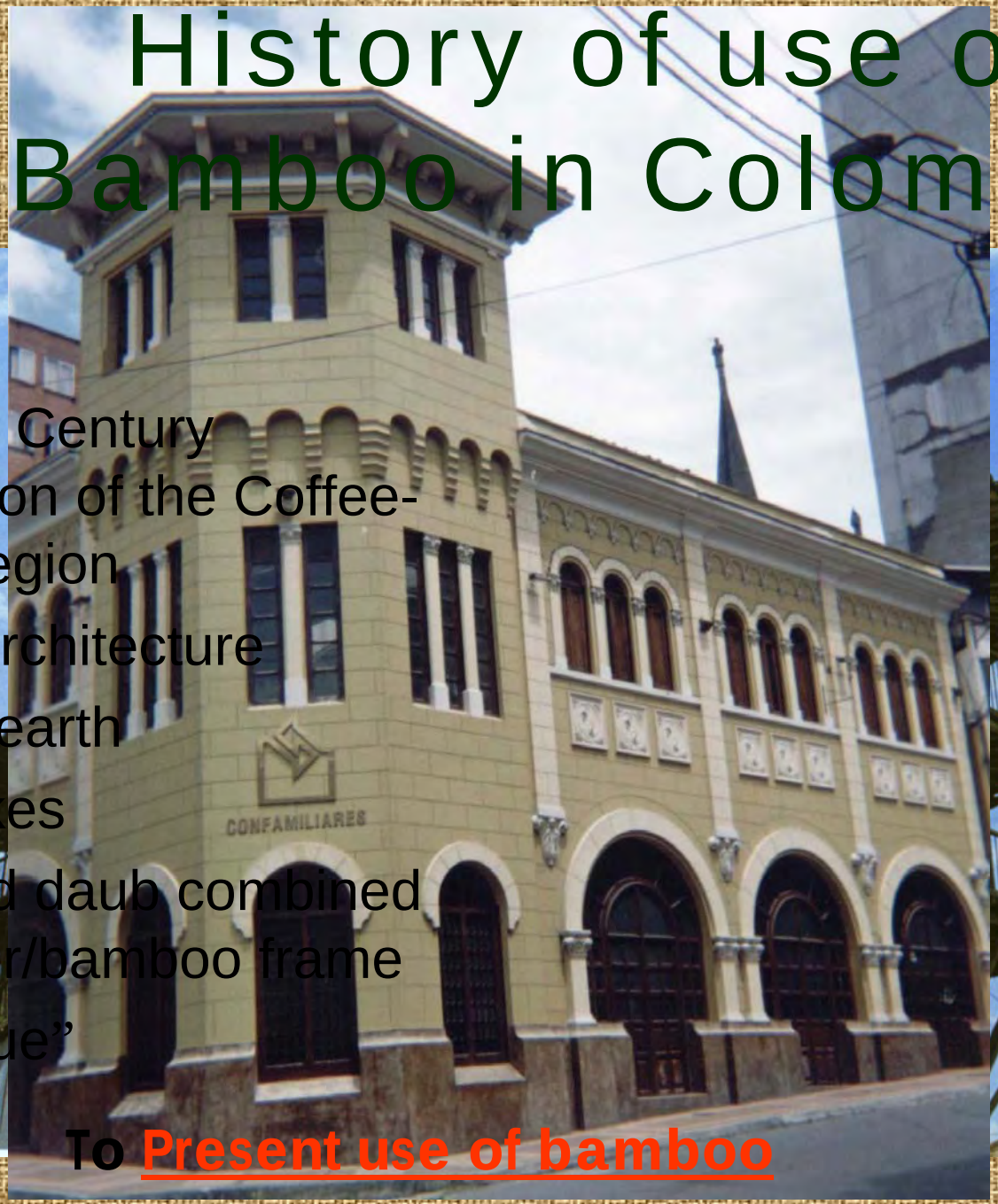
History of use of Bamboo in Colombia



- In the 19th Century Colonization of the Coffee-growing region
- Spanish architecture
- Rammed earth
- Earthquakes
- Wattle and daub combined with timber/bamboo frame
- “Bahareque”

To **Present use of bamboo**

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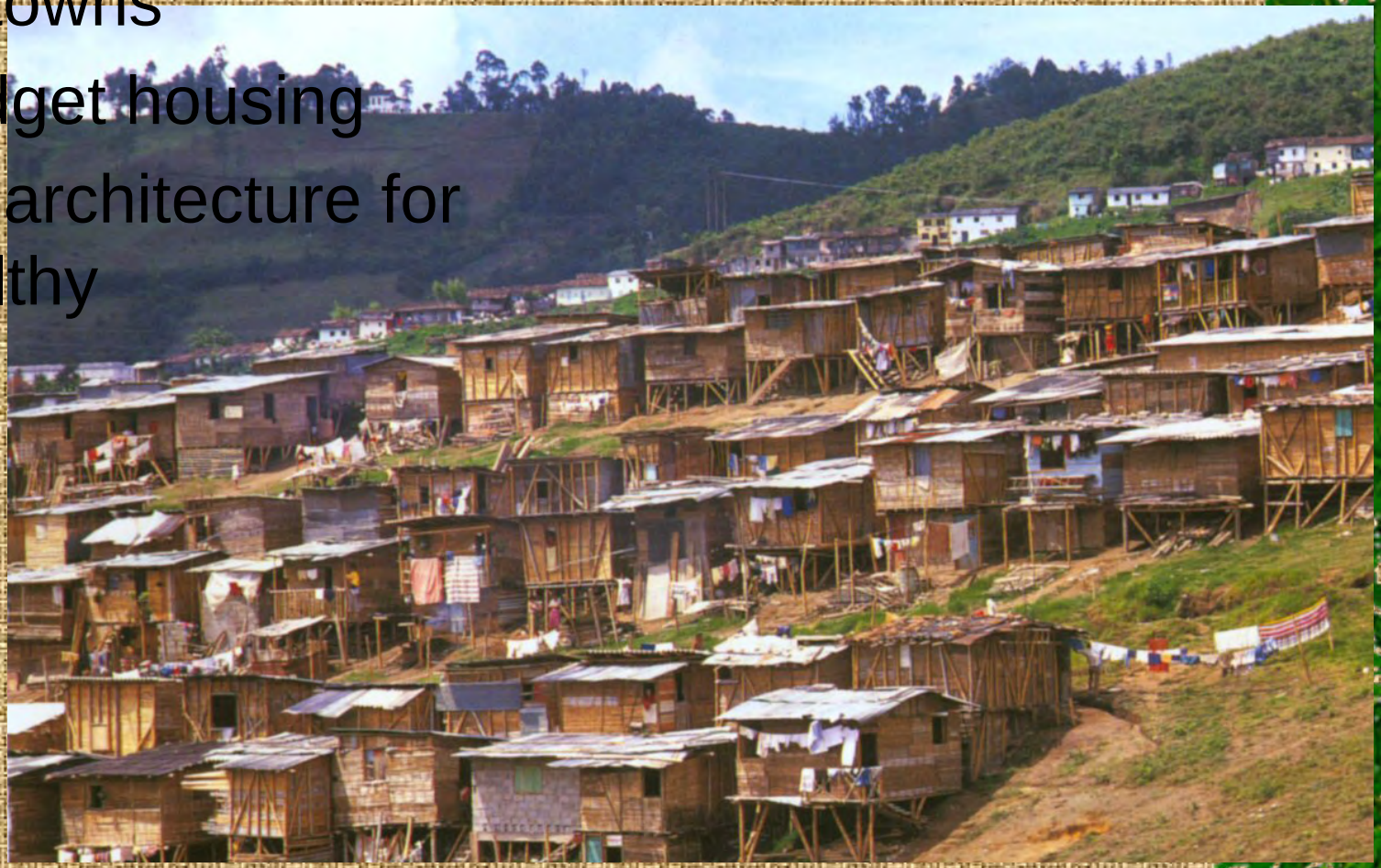
Present use of Bamboo in Colombia

- Shanty towns
- Low budget housing
- Modern architecture for the wealthy



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The 1999 Coffee-growing Region earthquake

- Damage to RC structures

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The 1999 Coffee-growing Region earthquake

- How did bamboo structures perform?

Figure 2. A house at the "Experimental Centre for Bamboo Construction". Other new bamboo structures also performed well during this earthquake

shortcomings were identified in partially constructed houses.

There were several types of construction for low-rise buildings. The traditional bahareque buildings

performance of modern bamboo structures. An experimental centre for bamboo construction was located very close to the epicentre but only very minor damage was observed (Fig. 2).

beams. Again there was negligible structural damage but the deflection of the frame had still been sufficient to cause moderate damage to masonry infill.

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Figure 2. A house at the “Experimental Centre for Bamboo Construction”. Other new bamboo structures also performed well during this earthquake

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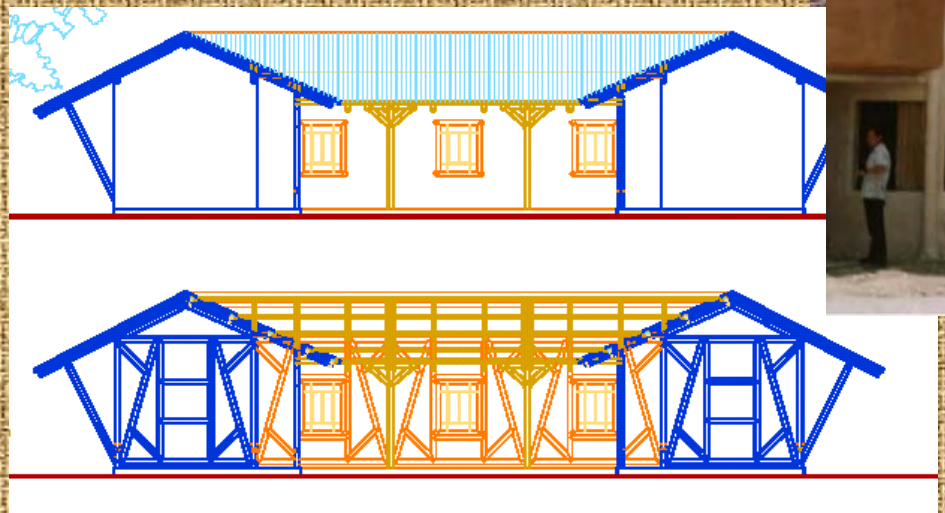
Bamboo housing projects after the earthquake

- Houses donated by: German, Spanish, Italian and Swiss development agencies…
- …and Colombian NGOs working with government funds



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Bamboo School

- Donated by UNICEF and several Worker's Trade Unions
- Designed by …
- …Architect Simón Vélez

Bamboo School

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Development of the

”

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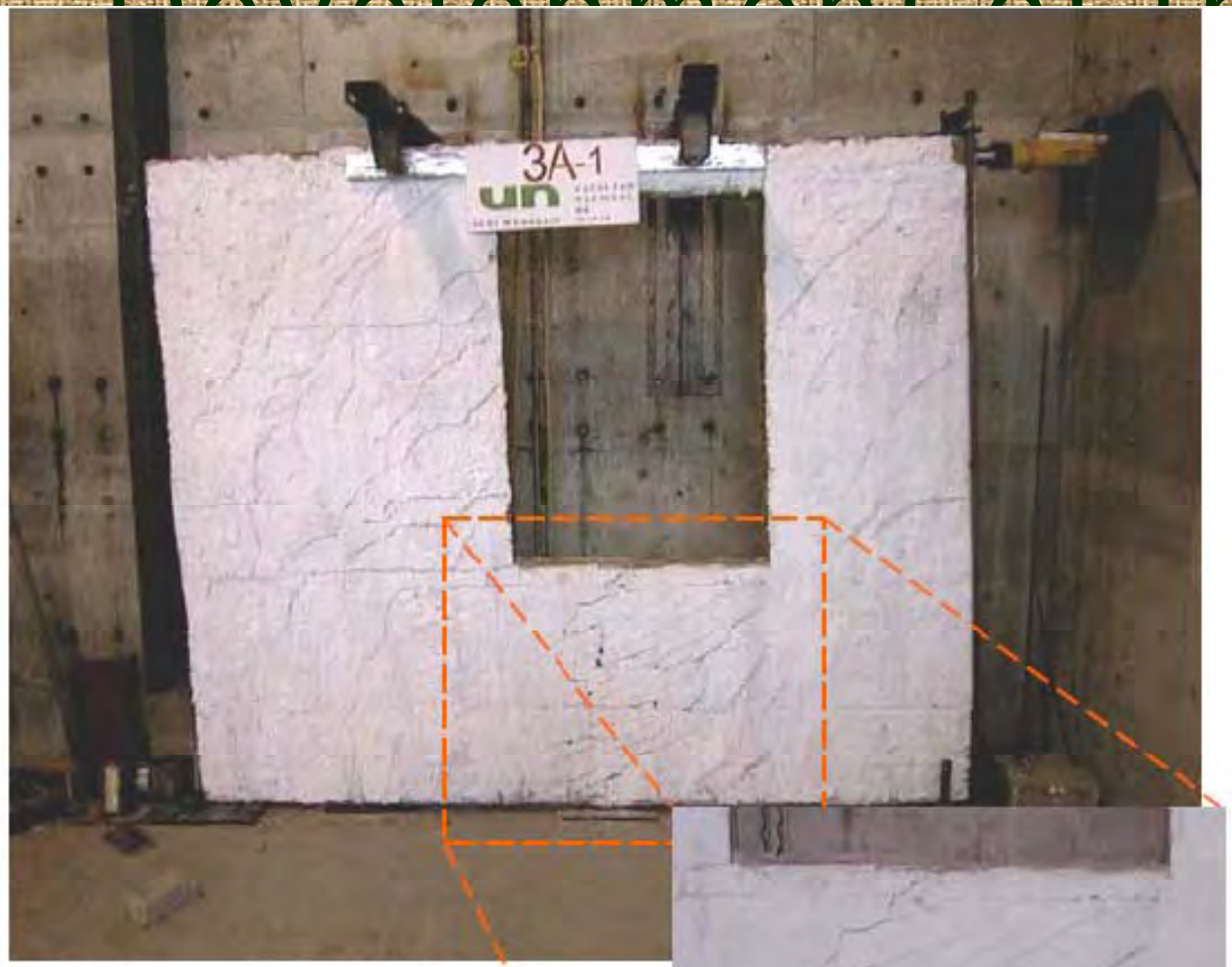


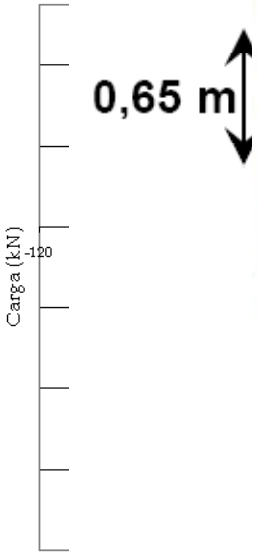
2,45 m

0,65 m

a) Vista general de la probeta en el SER

b) Detalle de la concentración de daño en el alféizar

Figura 19. Probeta 3A-1 después de la falla.



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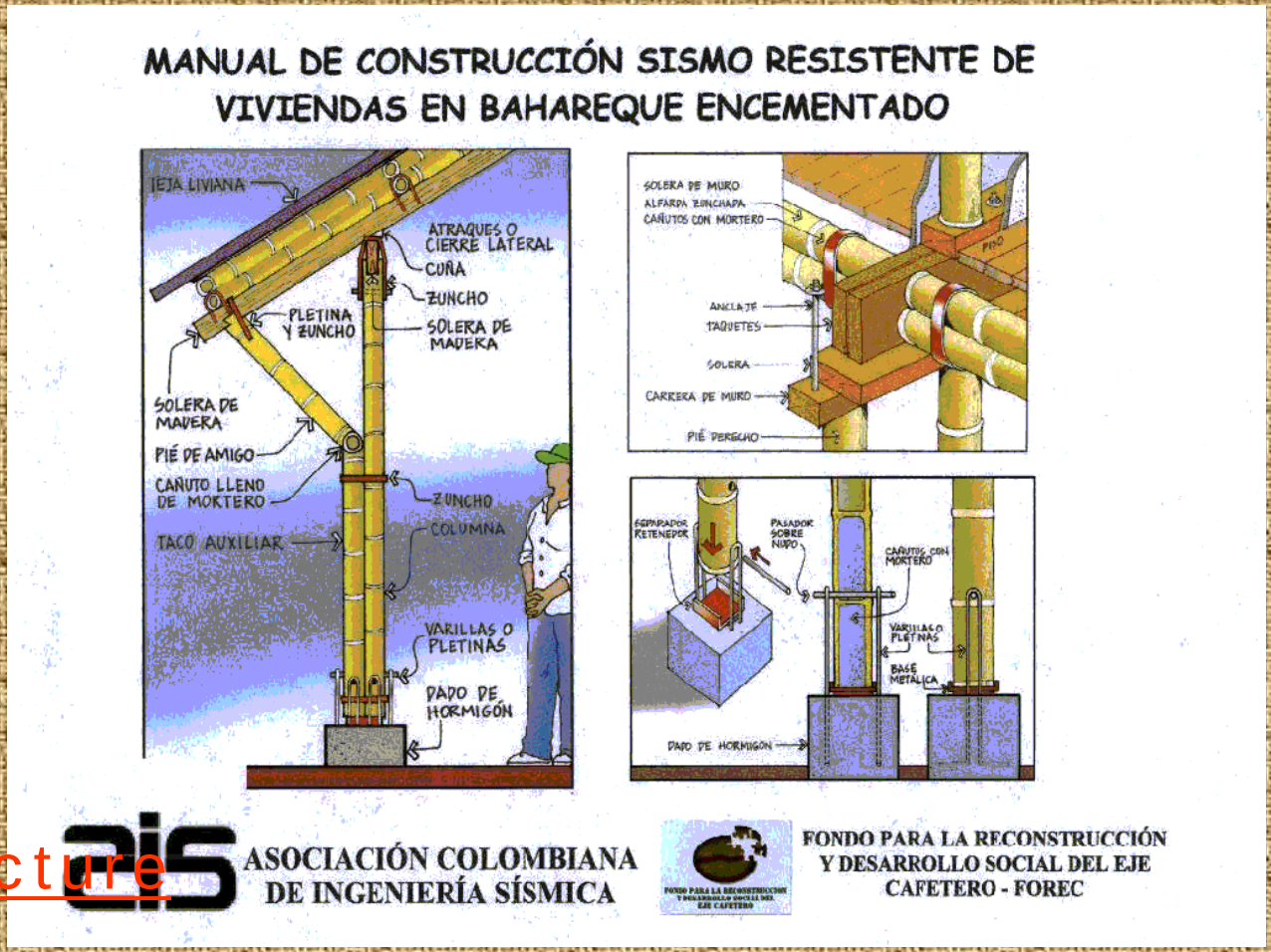
The World's First (?) Bamboo Code

- Earthquake-resistant mortar-rendered bahareque construction handbook.



Modern Architecture

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Modern Bamboo Architecture

- Many Colombian architects have worked with bamboo…
- Óscar Hidalgo
- Simón Vélez

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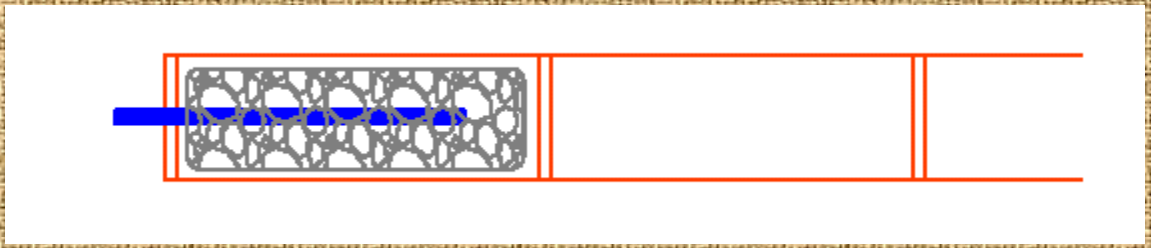
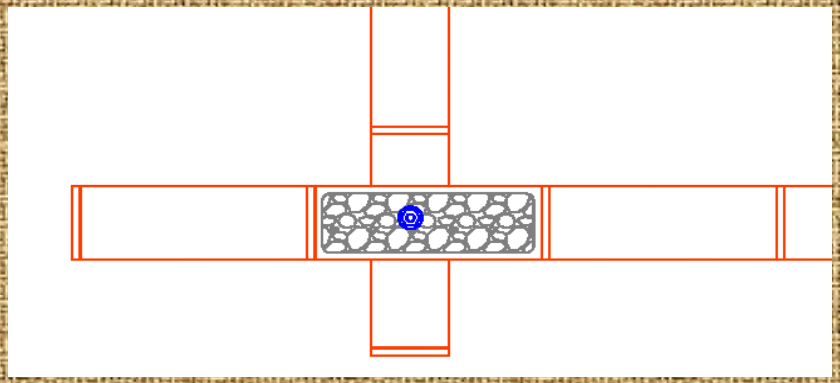
The work of Simón Vélez

- The grouted connection
- This simple connection allowed Simón…





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The work of Simón Vélez

- … to build this.
- This technique was mastered…

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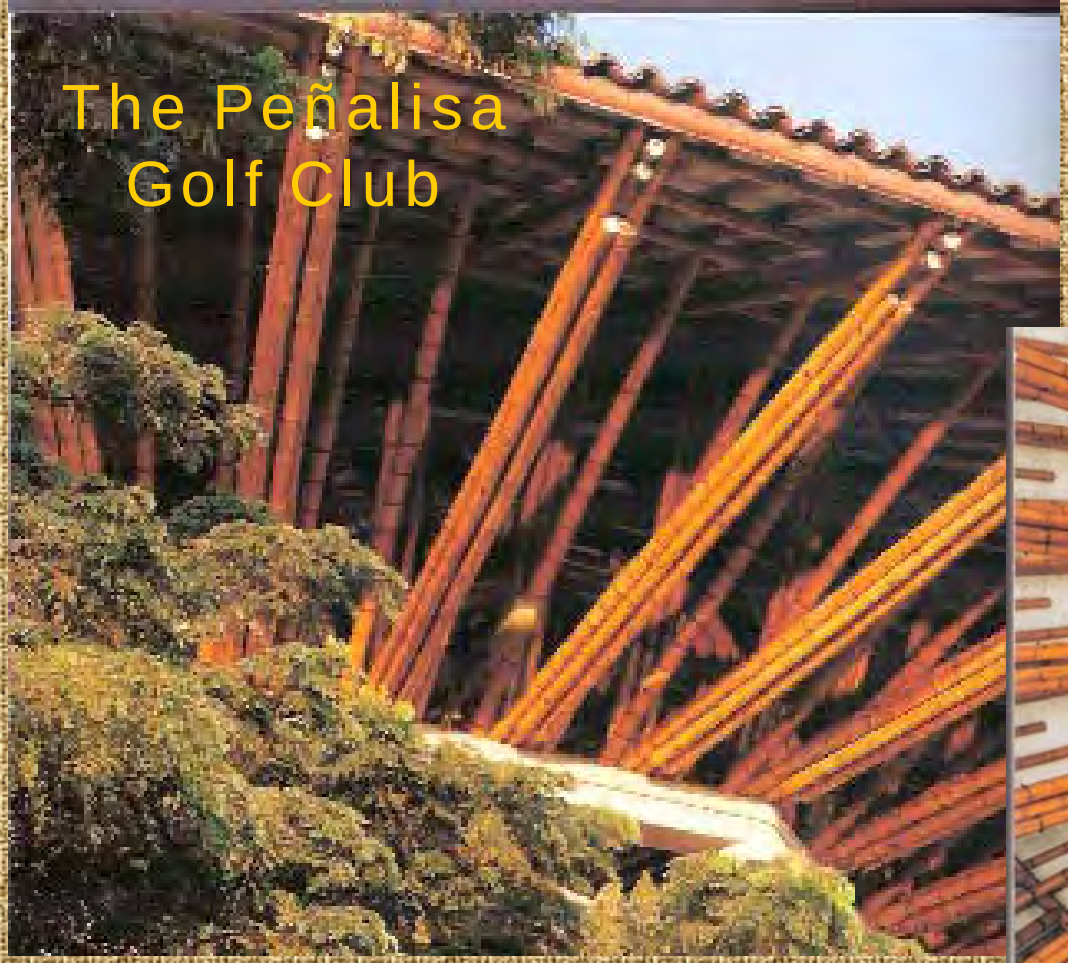
- ...and this enabled Simon to build this.

The Peñalisa Golf Club



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- This is possibly the world's largest bamboo structure.

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The Bamboo Pavilion

ZERI commissioned Simon to design and build a bamboo structure for Expo Hanover.

The Bamboo

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The Temporary Church

- The temporary cathedral of Pereira

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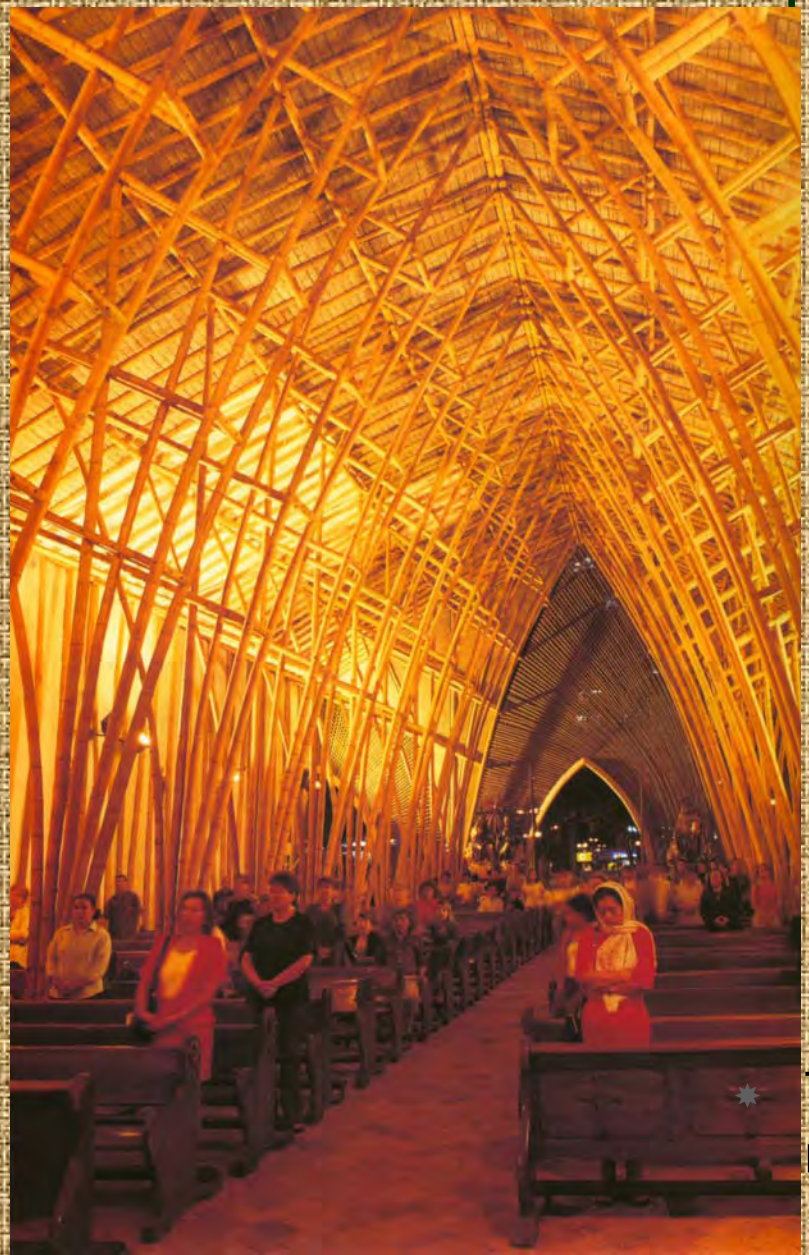
The Temporary Church



This structure was demolished when the main cathedral was reopened.

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The Jenny Garzón Bridge

- 45.6m span footbridge over one of Bogotá's most important avenues.

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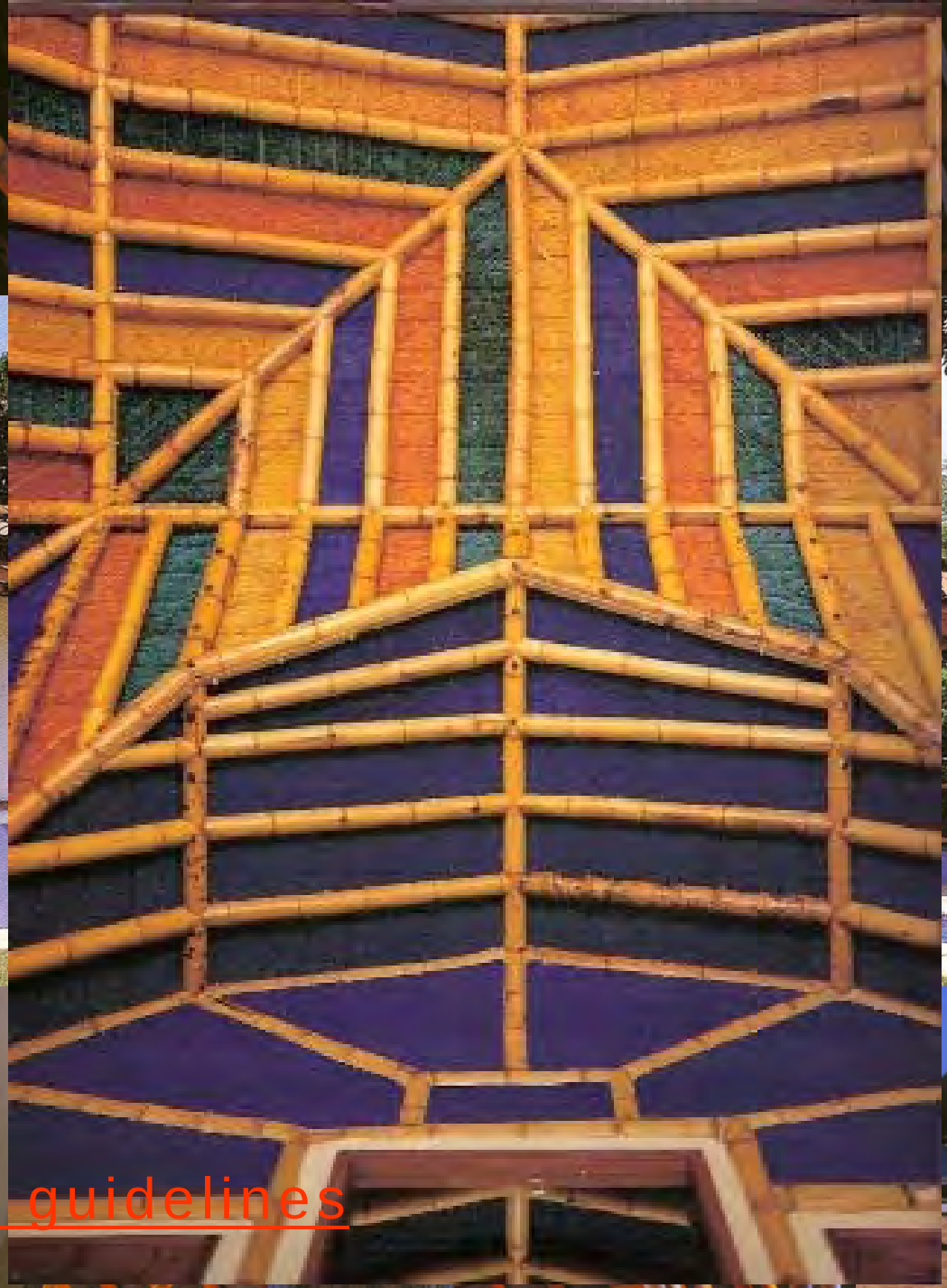

To Structural guidelines

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Guidelines for Structural use of bamboo

- Drawn from direct and indirect experience

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Disadvantages

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Seismic design

- High strength to weight ratio √
- Flexible ≈
- Not ductile X
- but ductile connections can be introduced √
- Traditional techniques have shown good results √
- Flexibility ≠ ductility

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Connection Design

- A few definitions first

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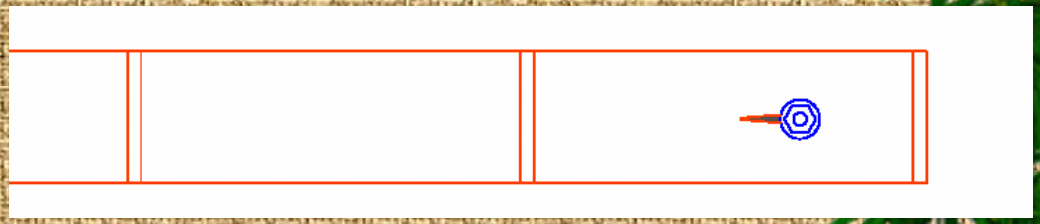
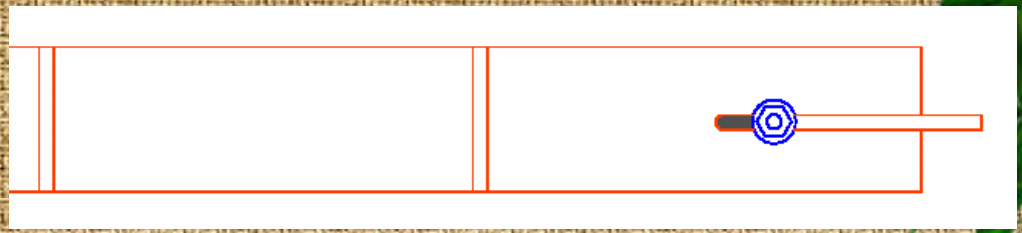
Mechanical Fasteners

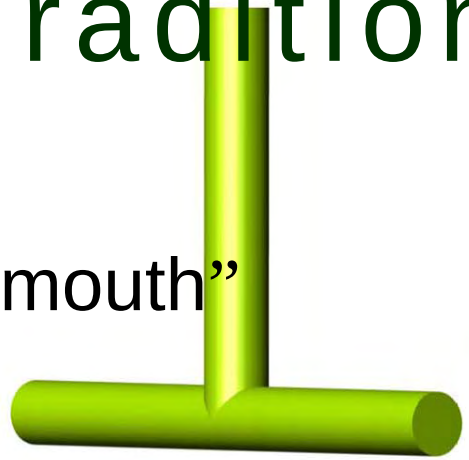
- Mechanical fastene
  - Nails
  - Screws
  - Bolts
  - Dowels
  - Pegs
- Splitting failure
- Shear failure
- Bearing failure



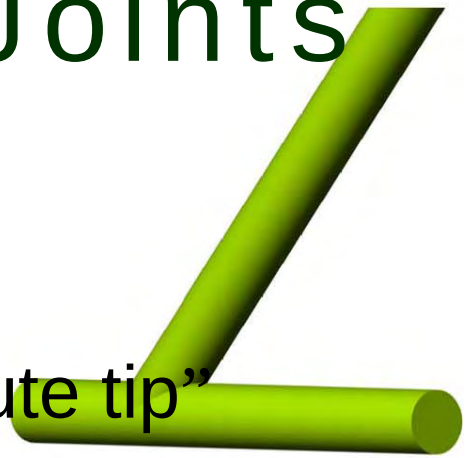


Carpentry or Traditional Joints

- “Fish mouth”



- “Flute tip”



- Handsome
- Labour intensive

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Connection Design

- Complete joint detail
- Fasteners
- Carpentry joints
- Gusset plates
- Cement grout
- Geometry

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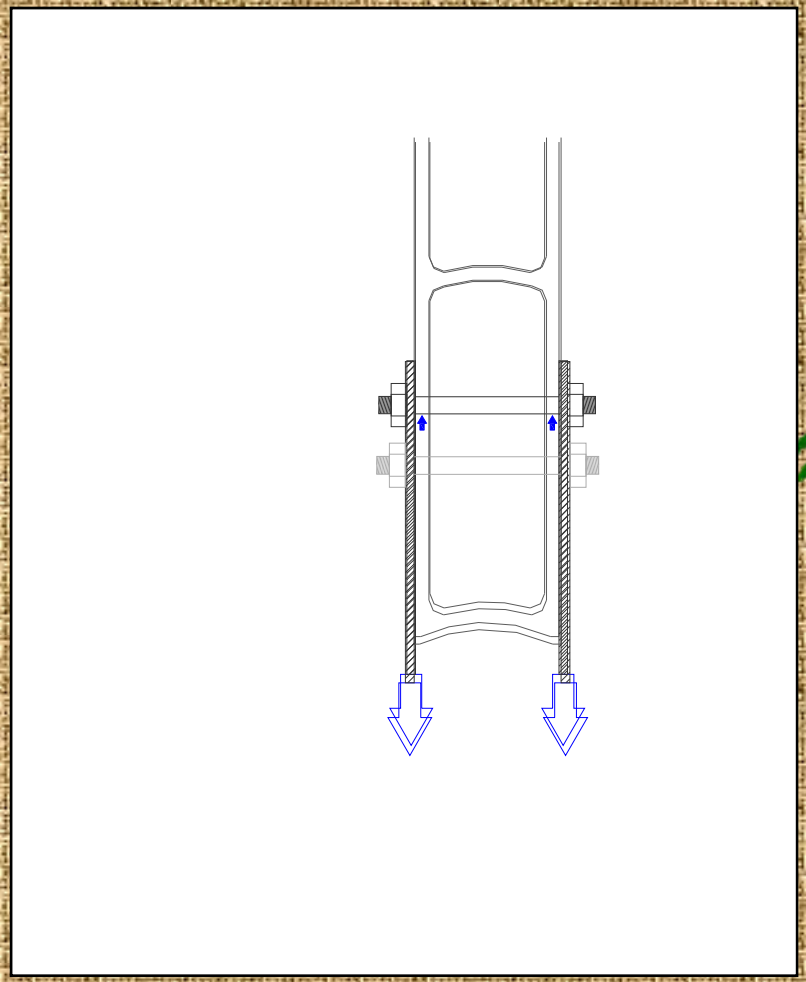
The grouted connection

- A typical shear connection
- 12.7mm fastener
- Fu = 10-13kN



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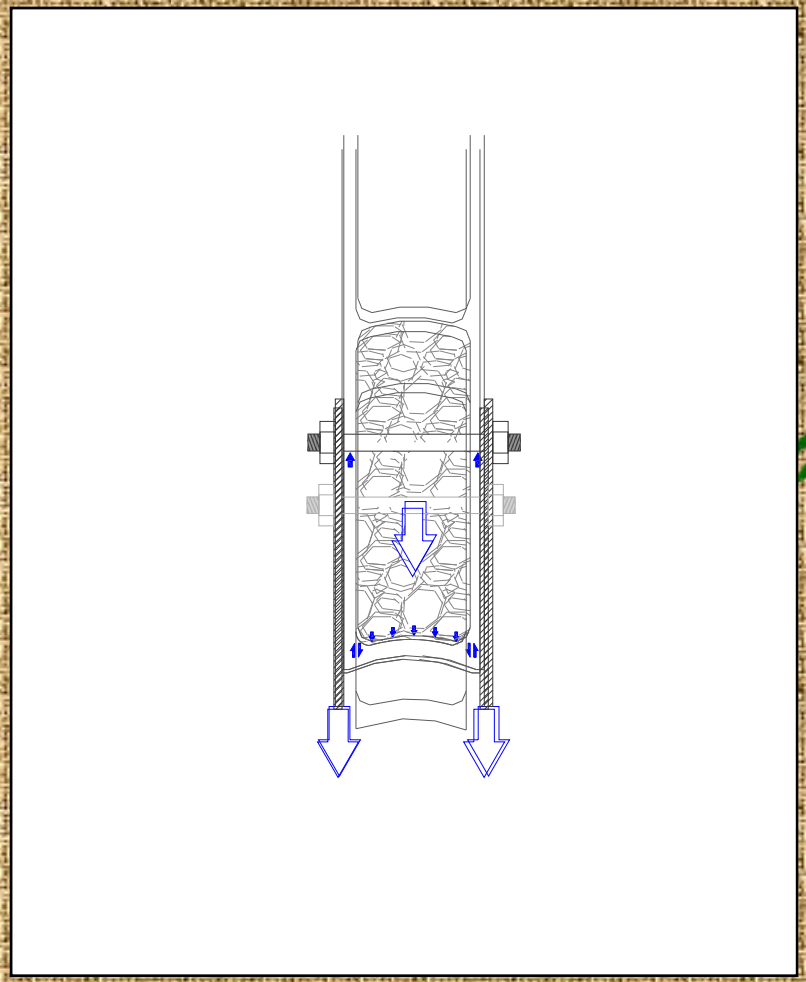
The grouted connection

- A grouted connection
- 12.7mm fastener
- Fu = 35kN



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The grou
connecti

- The improved grouted connection
- 12.7mm fastener
- + 6.35mm rebar pins
- Fu = 60kN

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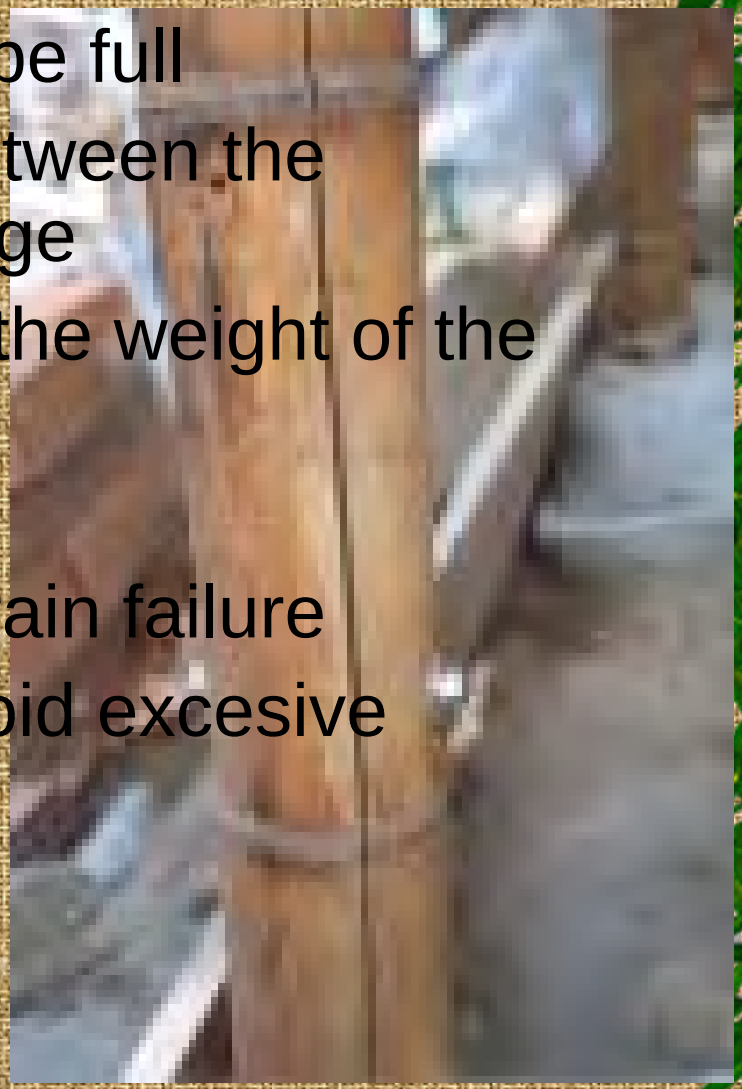
The grouted connection

- The whole internode must be full
- A node must be present between the fastener and the loaded edge
- This connection increases the weight of the structure
- Reduces crushing failure
- Reduces tension perp to grain failure
- Bamboo must be dry to avoid excesive shrinkage
- Use cement grout sparsely



To the future of bamboo

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The future of bamboo in construction...

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The "*Bambusa*" housing project

- First housing project to the code
- 80 houses
- Donated by US-AID for tenants that lost their homes
- Structure cost US$2200 approx each
- 40% larger than traditional build (but tiny all the same 35m^2)

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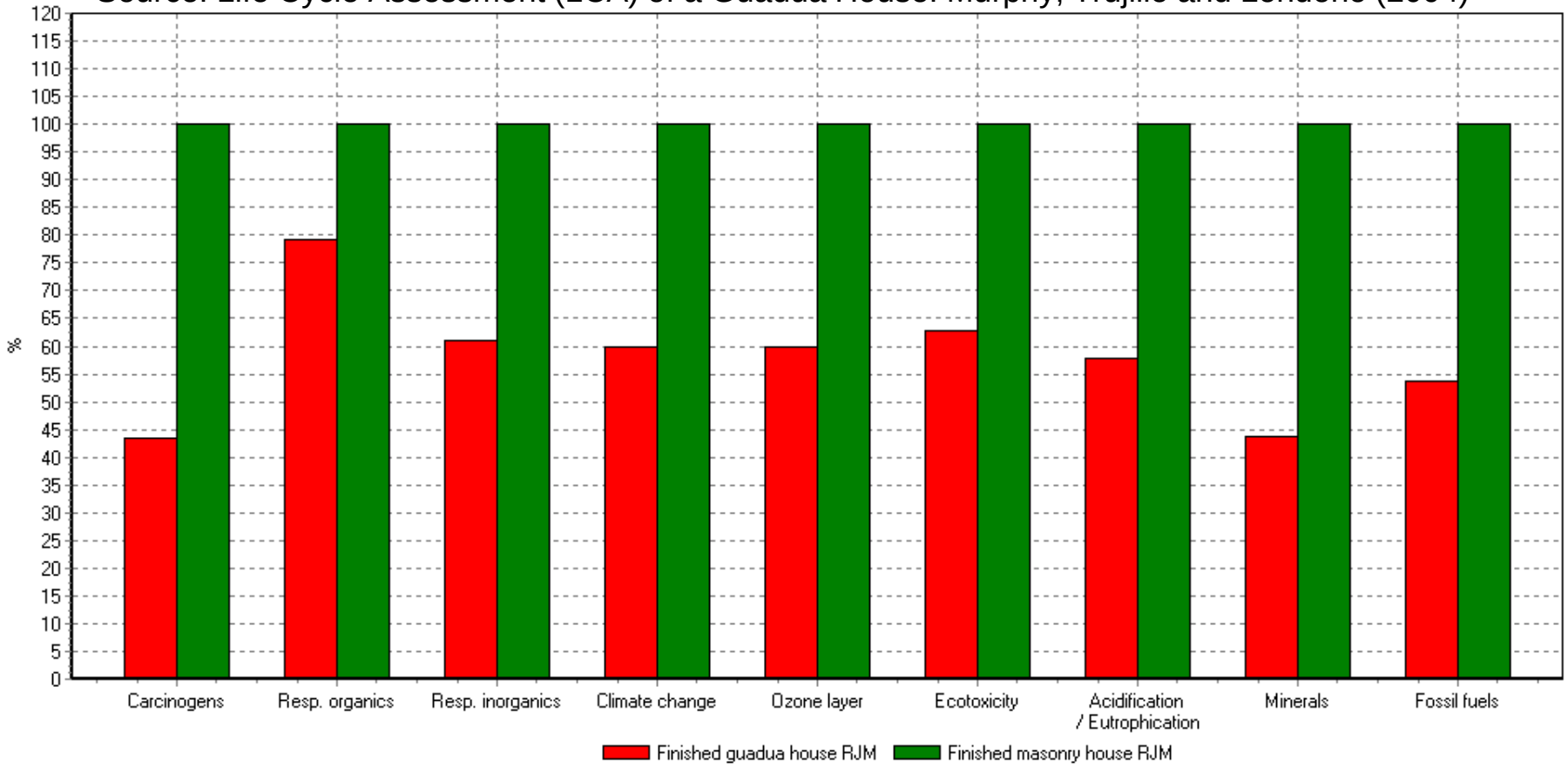
Life Cycle assesment for a "*Bambusa*" house

Source: Life Cycle Assessment (LCA) of a Guadua House. Murphy, Trujillo and Londoño (2004)



Comparing 1 p assembly 'Finished guadua house RJM' with 1 p assembly 'Finished masonry house RJM'; Method: Eco-indicator 99 (H) V2.1 excl. Land Use & Radn. / Europe EI 99 H/A / characterization

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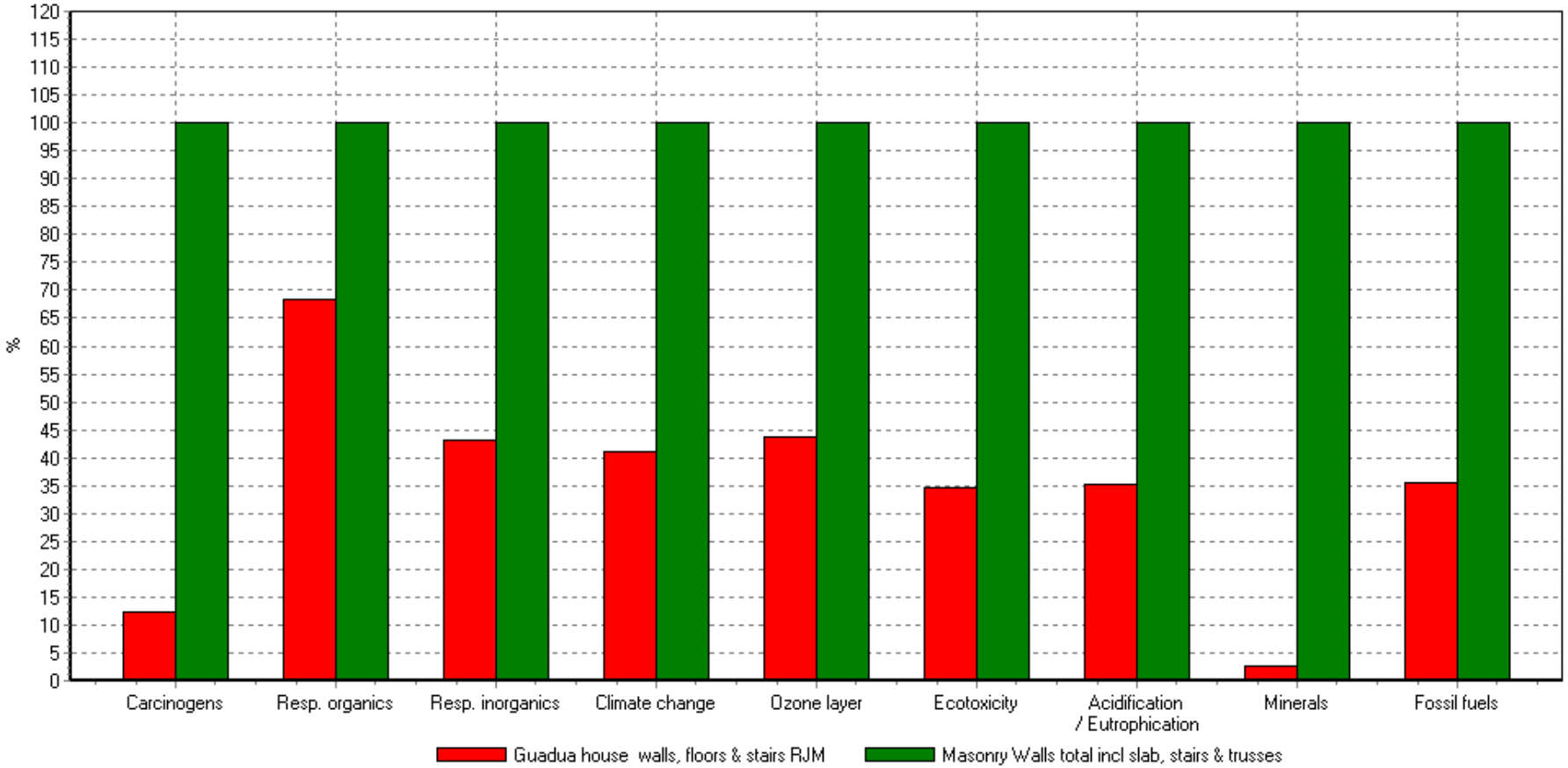
Life Cycle assesment for a "*Bambusa*" house

Source: Life Cycle Assessment (LCA) of a Guadua House. Murphy, Trujillo and Londoño (2004)



Comparing 1 p assembly 'Guadua house walls, floors & stairs RJM' with 1 p assembly 'Masonry Walls total incl slab, stairs & trusses'; Method: Eco-indicator 99 (H) V2.1 excl. Land Use & Radn. / Europe EI 99 H

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What the future holds

- Developing countries relief and development programmes
  - Housing
  - Schools
  - Bridges
  - Medium rise buildings
- Support from developed countries is needed for
  - Further research
  - Further code development
  - Promotion of the material and construction systems
- Can occupy a role in modern construction as a sustainable “hard wood”
  - Laminates
  - Sheathing
  - Joists
  - Anywhere where timber can go
- Space frames
  - Temporary structures
  - Permanent structures

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Contacts

- Worldwide
  - The International Network for Bamboo and Rattan (INBAR)
- In the UK
  - Buro Happold
  - TRADA Technology
- In Colombia
  - Colombian Earthquake Engineering Association (AIS)
  - Colombian Bamboo Society (Sociedad Colombiana del Bambú)

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Further reading

Some titles available in amazon.co.uk

- Grow your own house
- Tropical bamboo
- Mechanical properties of Bamboo
- New Bamboo Design and Architecture
- Building with Bamboo: A handbook

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Acknowledgments

- Villegas Editores
- Colombian Bamboo Society - Ximena Londoño
- AIS – Luis Felipe López and Samuel Darío Prieto
- Universidad Nacional - Caori Takeuchi

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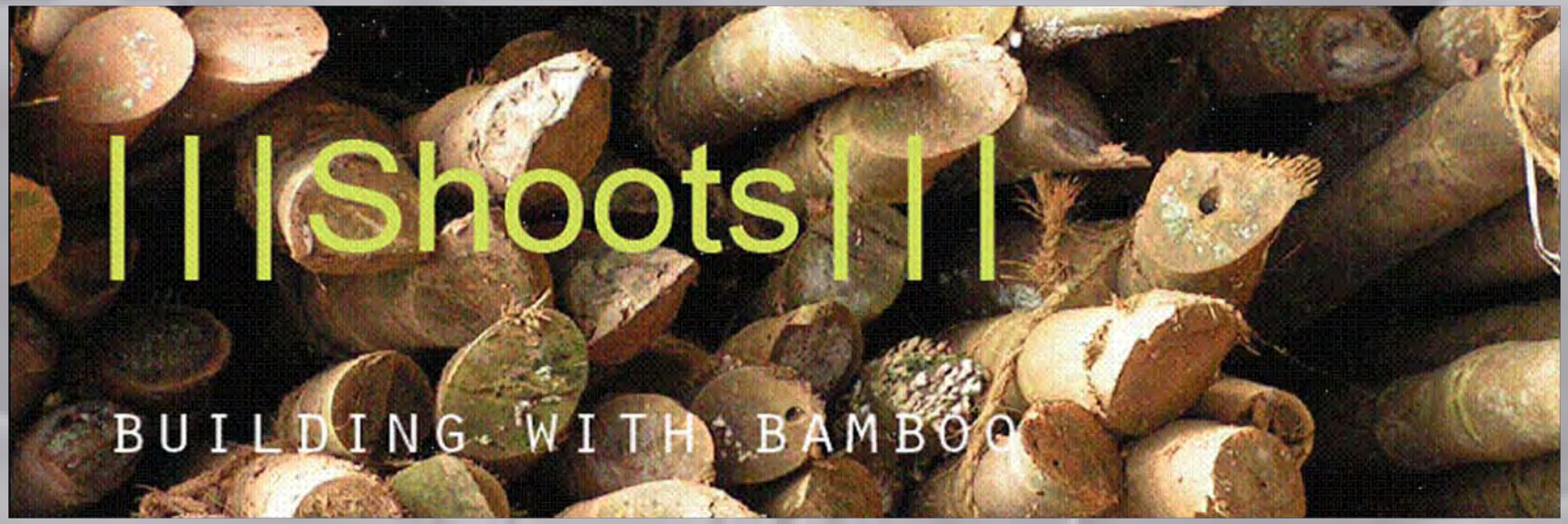
Many thanks

Any questions?



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Bamboo joints

MSc. Arch. Gema Diaz-Matthias

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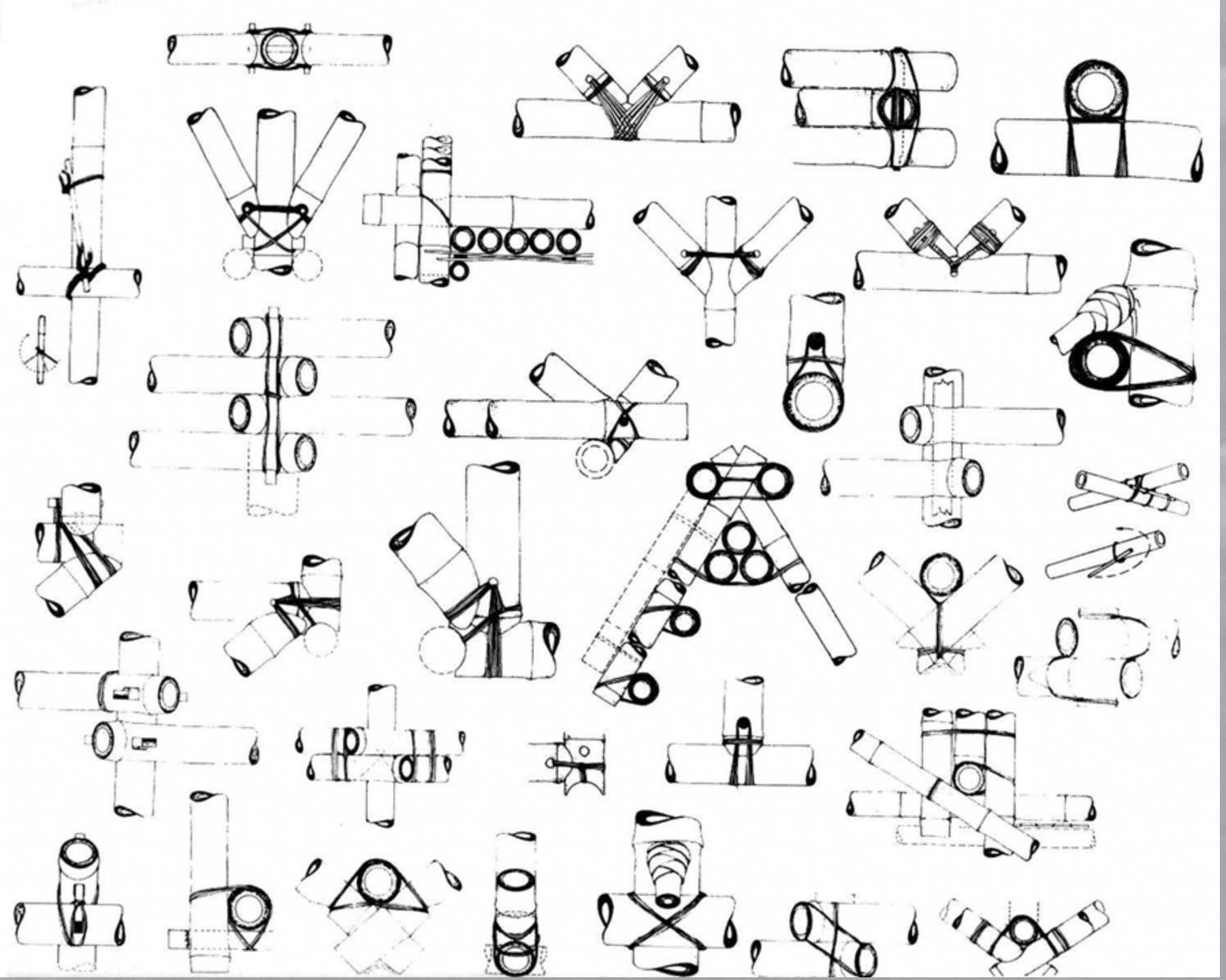
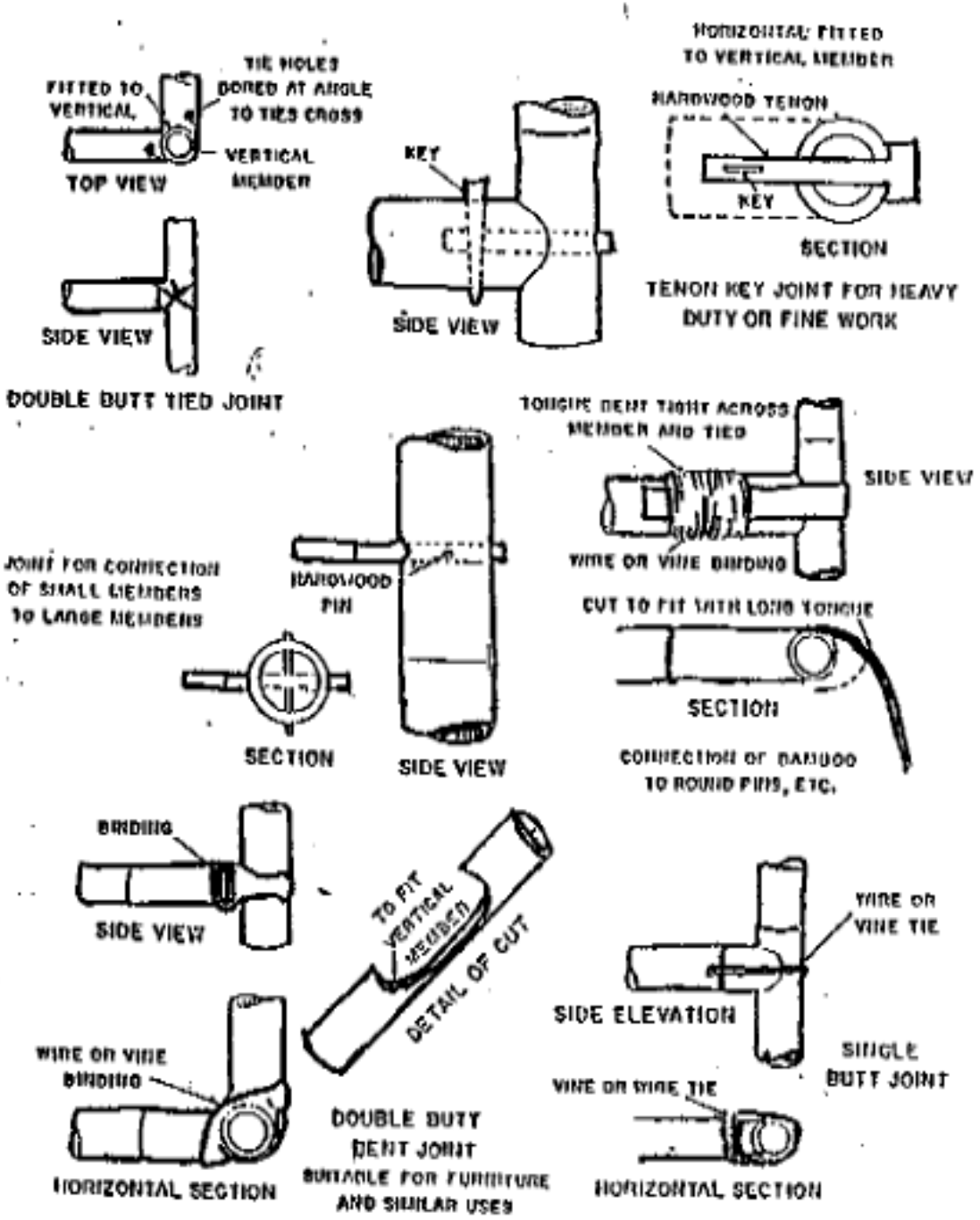


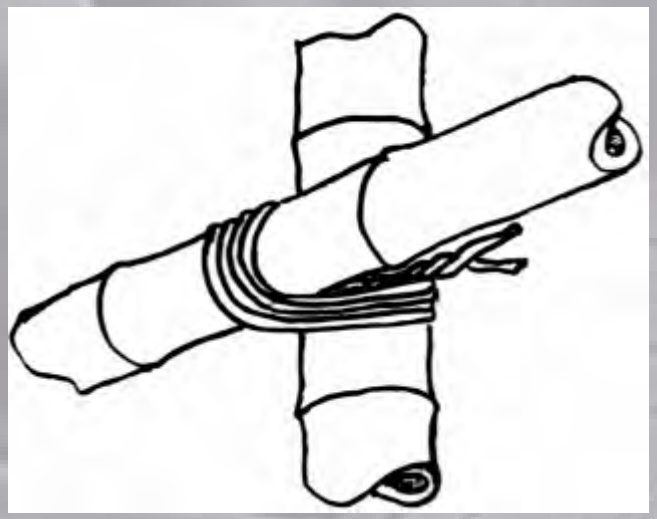
Traditional joints

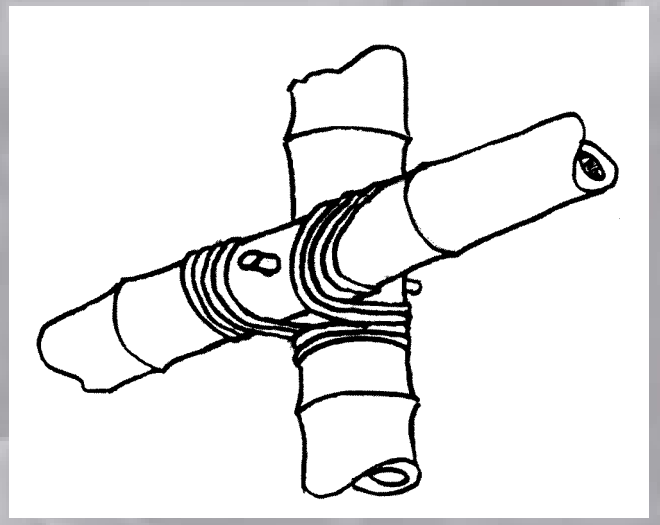
- Use of lashings (natural fibres or others) and/or pegged joinery
- Specific cuts are important

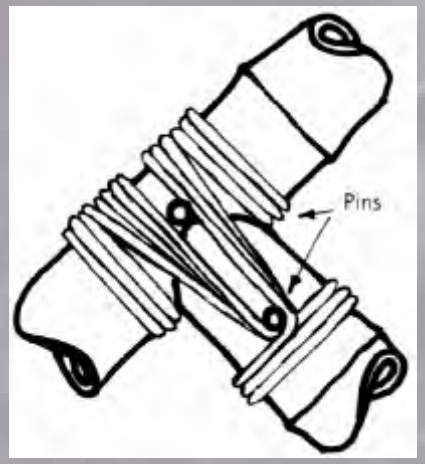
- Hand made
- Economical (in third world countries)

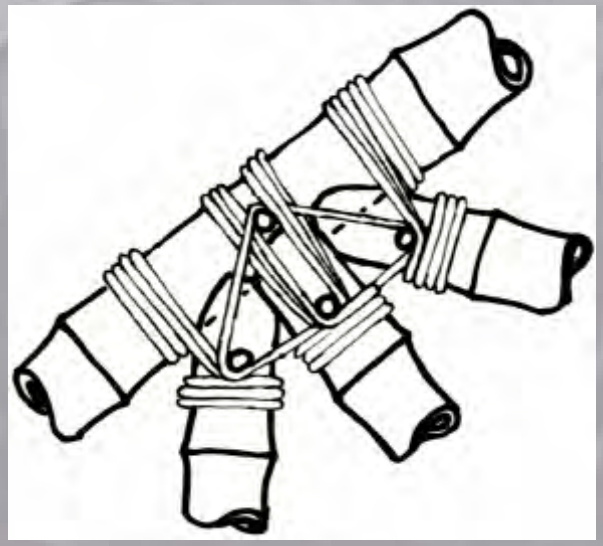
- Not very lasting
- Don't allow the application of greater forces

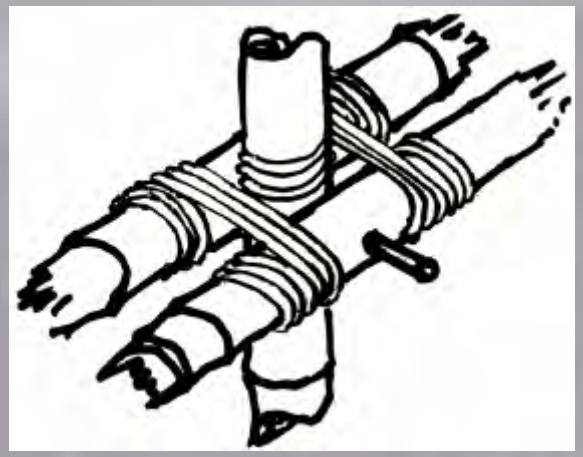

TIE HOLES BORED AT ANGLE TO TIES CROSS
FITTED TO VERTICAL
VERTICAL MEMBER
TOP VIEW
SIDE VIEW
DOUBLE BUTT TIED JOINT
KEY
SIDE VIEW
HORIZONTAL FITTED TO VERTICAL MEMBER
HARDWOOD TENON
KEY
SECTION
TENON KEY JOINT FOR HEAVY DUTY OR FINE WORK
TONGUE BENT TIGHT ACROSS MEMBER AND TIED
SIDE VIEW
WIRE OR VINE BINDING
JOINT FOR CONNECTION OF SMALL MEMBERS TO LARGE MEMBERS
HARDWOOD PIN
SECTION
SIDE VIEW
CUT TO FIT WITH LONG TONGUE
SECTION
CONNECTION OF BAMBOO TO ROUND PINS, ETC.
BINDING
SIDE VIEW
TO FIT VERTICAL MEMBER
DETAIL OF CUT
WIRE OR VINE TIE
SIDE ELEVATION
SINGLE BUTT JOINT
WIRE OR VINE BINDING
HORIZONTAL SECTION
DOUBLE BUTT DENT JOINT
SUITABLE FOR FURNITURE AND SIMILAR USES
VINE OR WIRE TIE
HORIZONTAL SECTION



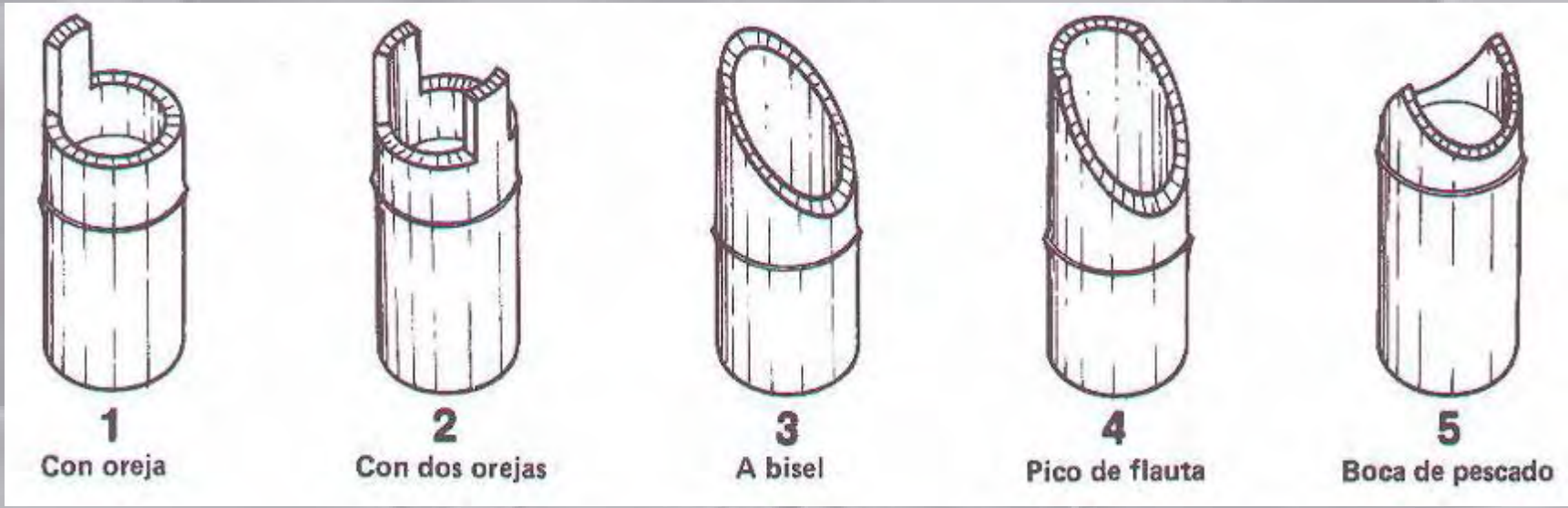



Pins





Traditional cuts



- With one ear
- With two ears
- With beveled edge
- Flute tip
- Fish mouth

Fish mouth

Fish mouth w/ear

Flute tip w/ear

Mizoram (India)

Improved traditional joints

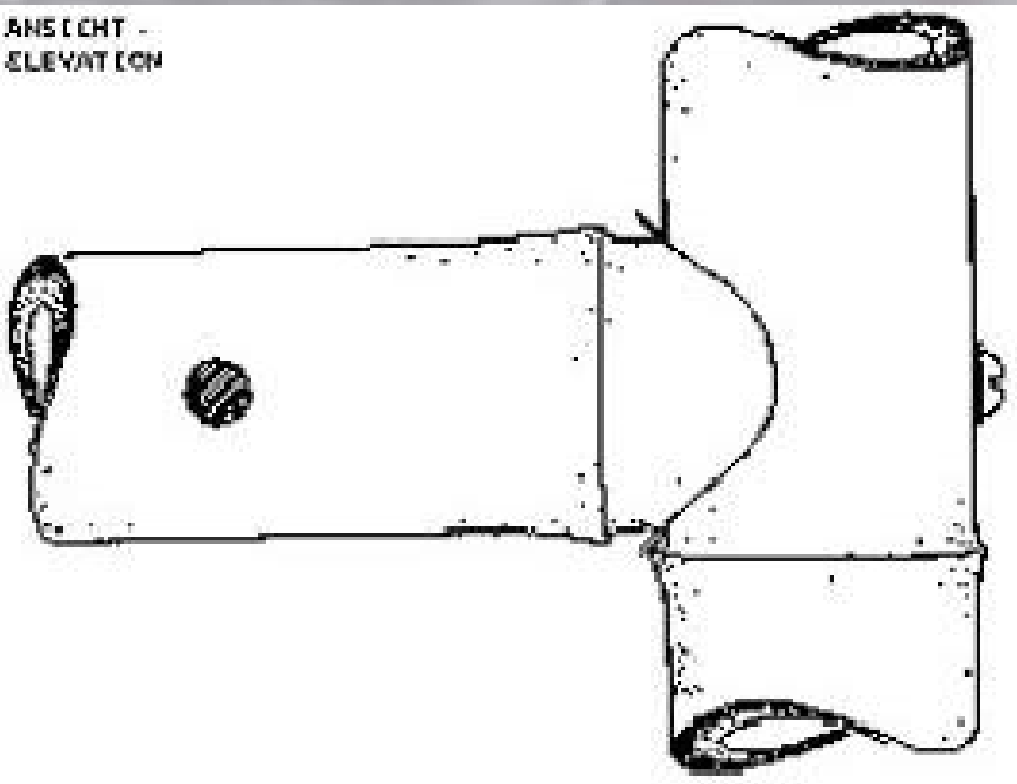
- Threaded rods, bolts and mortar is introduced

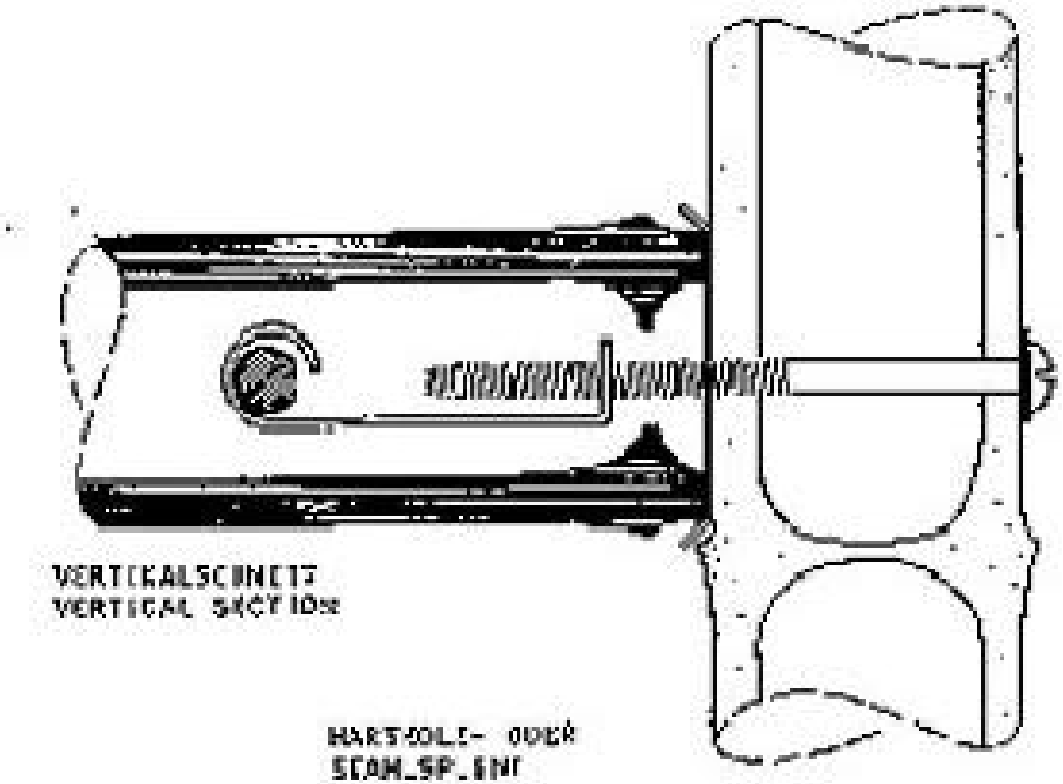
- They bear higher allowable forces
- They last longer

- The structure is not so light anymore
- Mortar and bamboo act in different ways

Improved fish mouth

ANSICHT -
ELEVATION



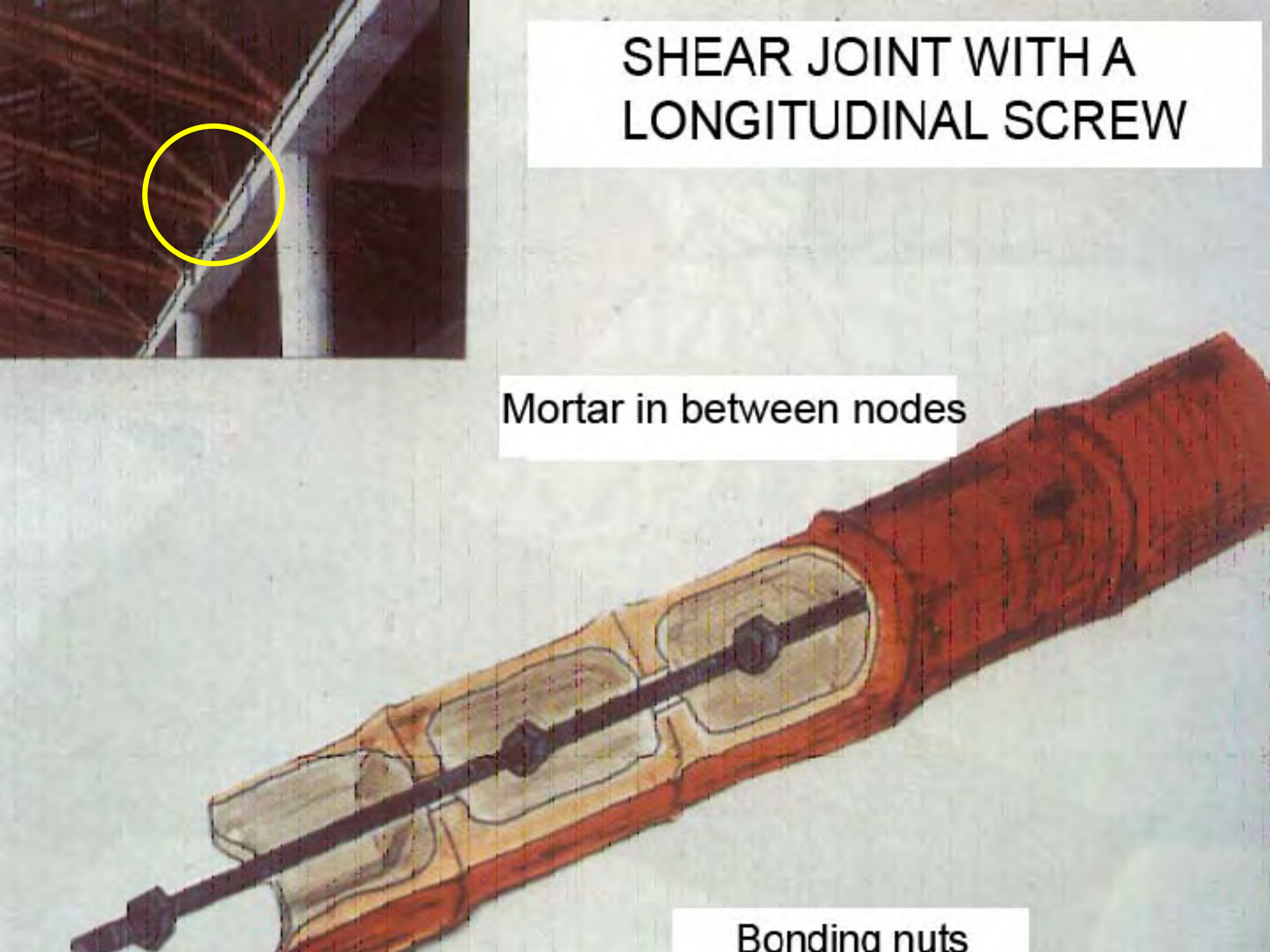


VERTIKALSCHNITT
VERTICAL SECTION

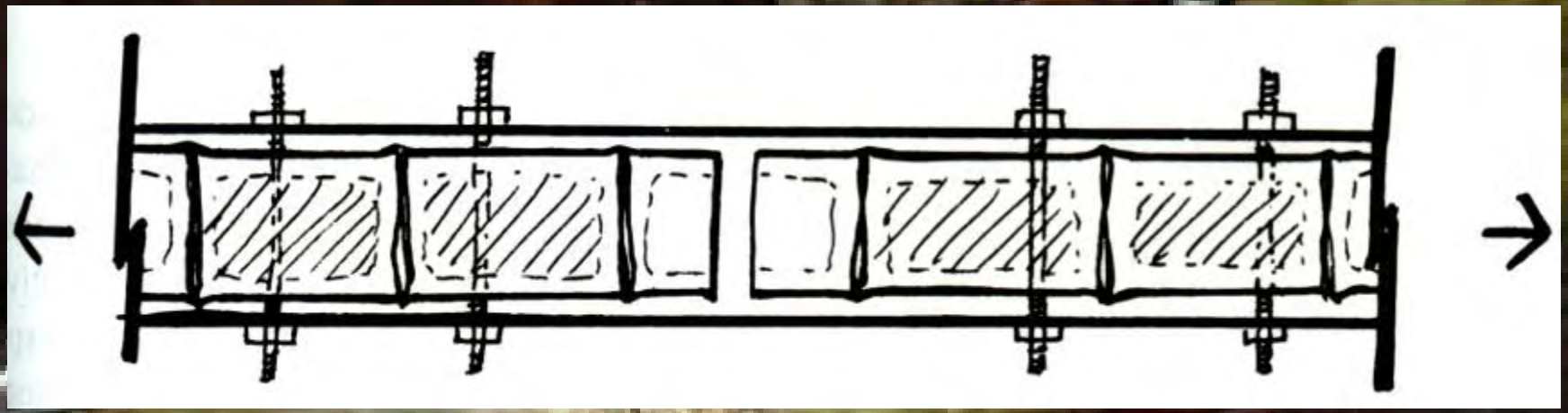
HARTSCHAUM- ODER
SCHAUMSTOFF

Flute tip w/support

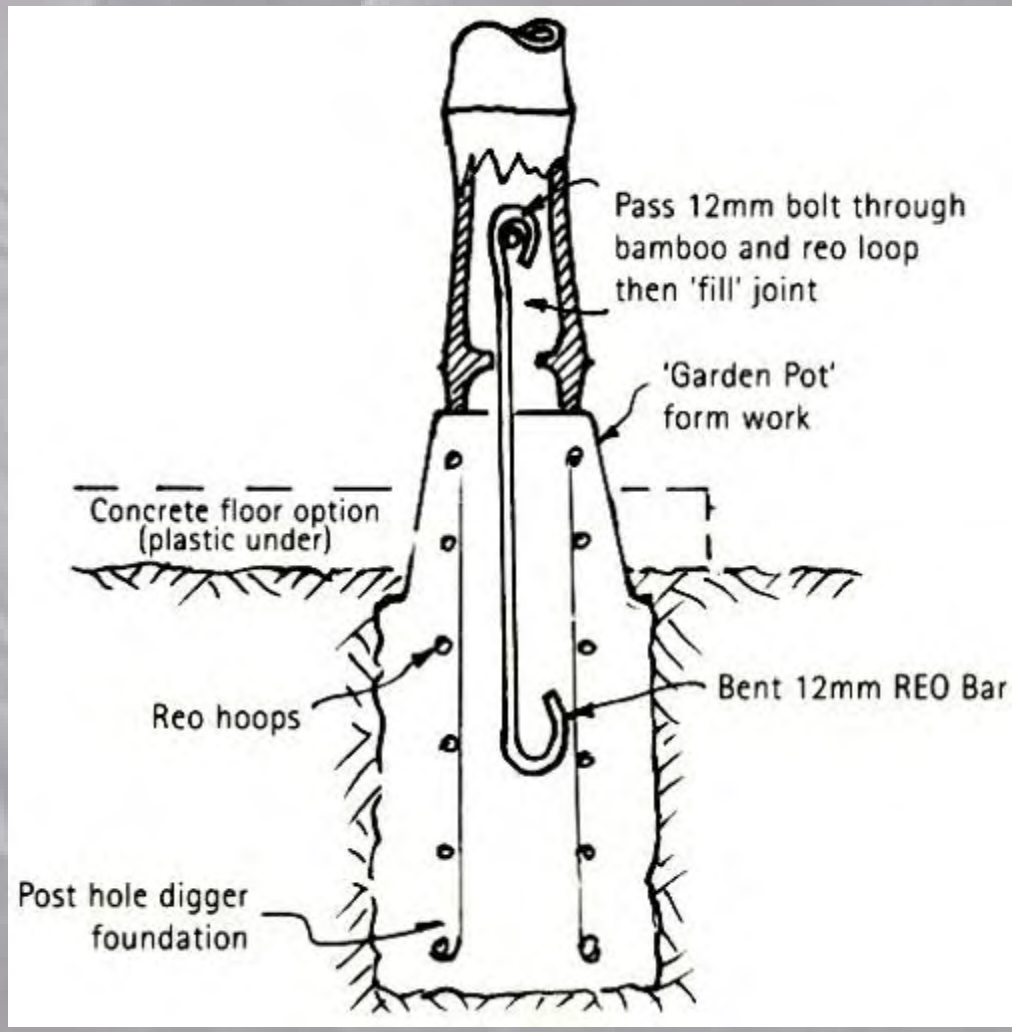
SHEAR JOINT WITH A LONGITUDINAL SCREW



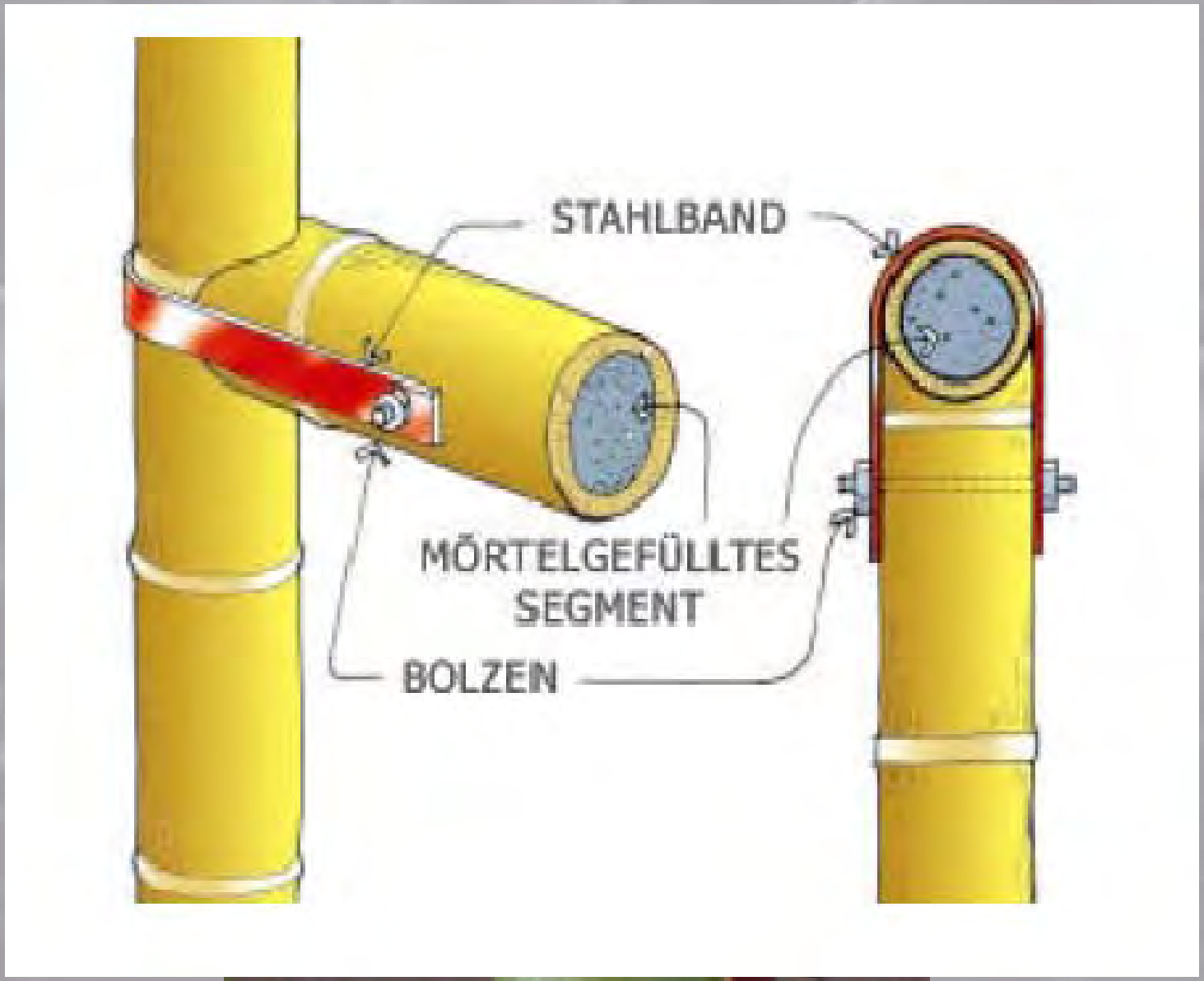
Longitudinal joints

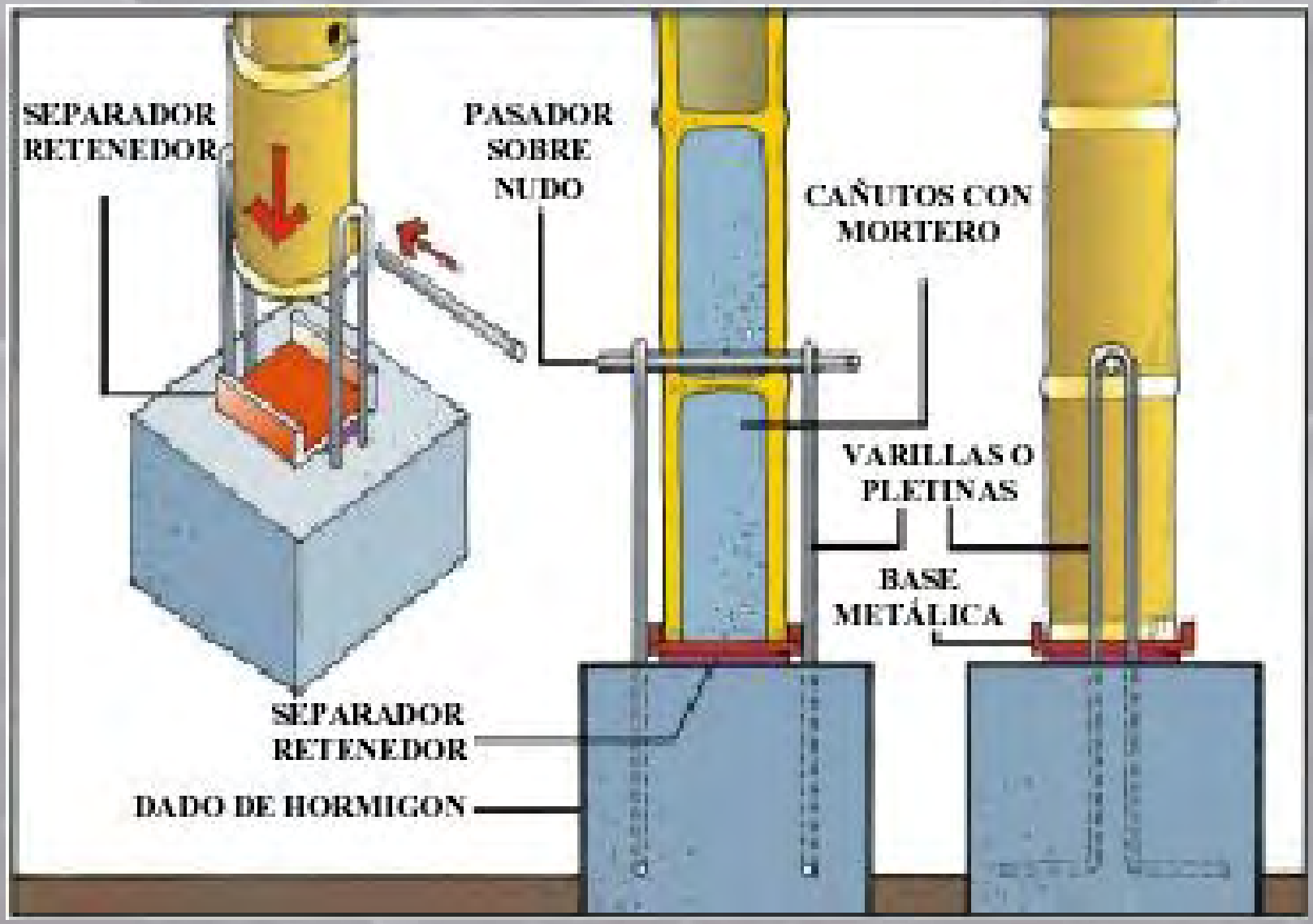


Foundations joints

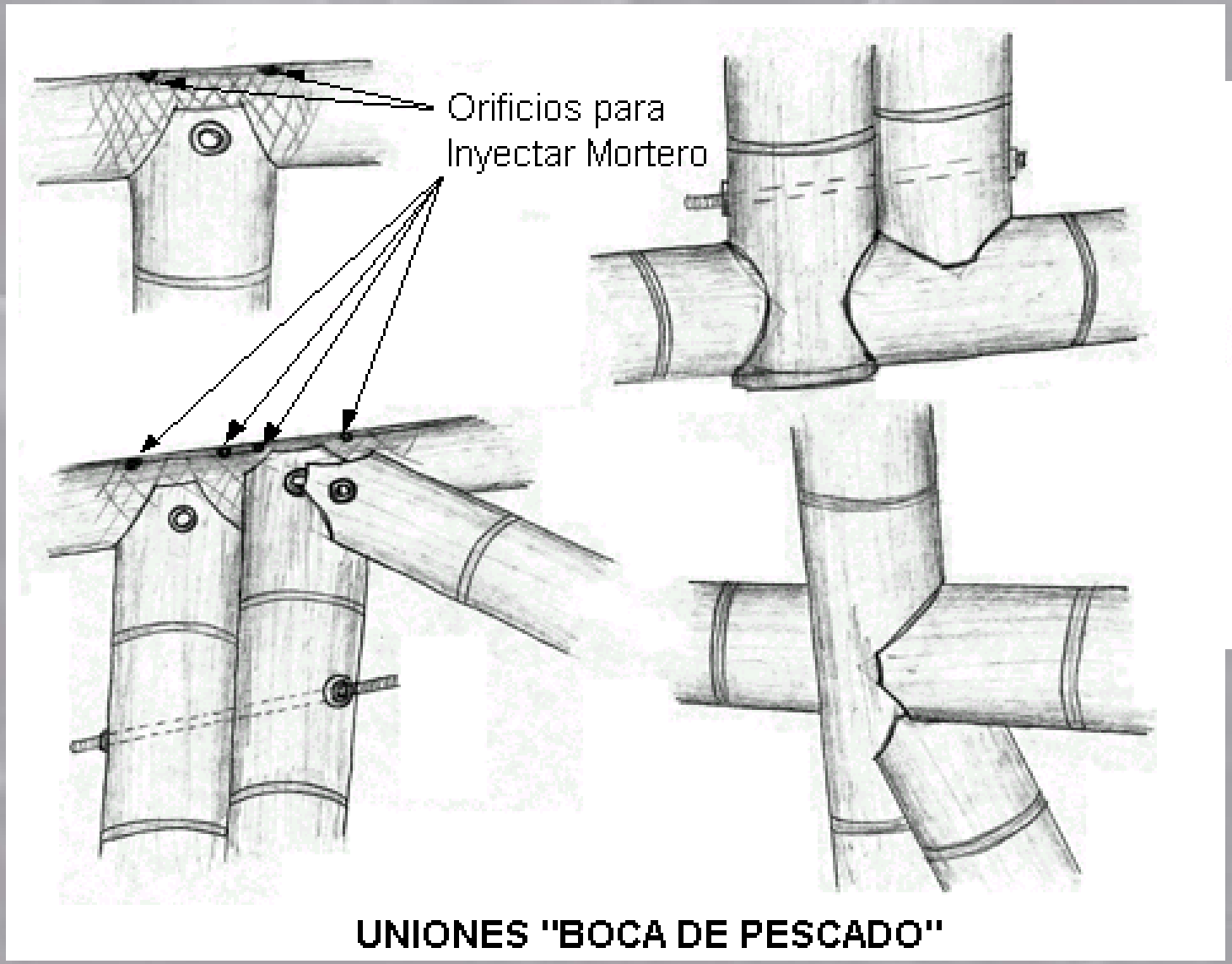


Other variants

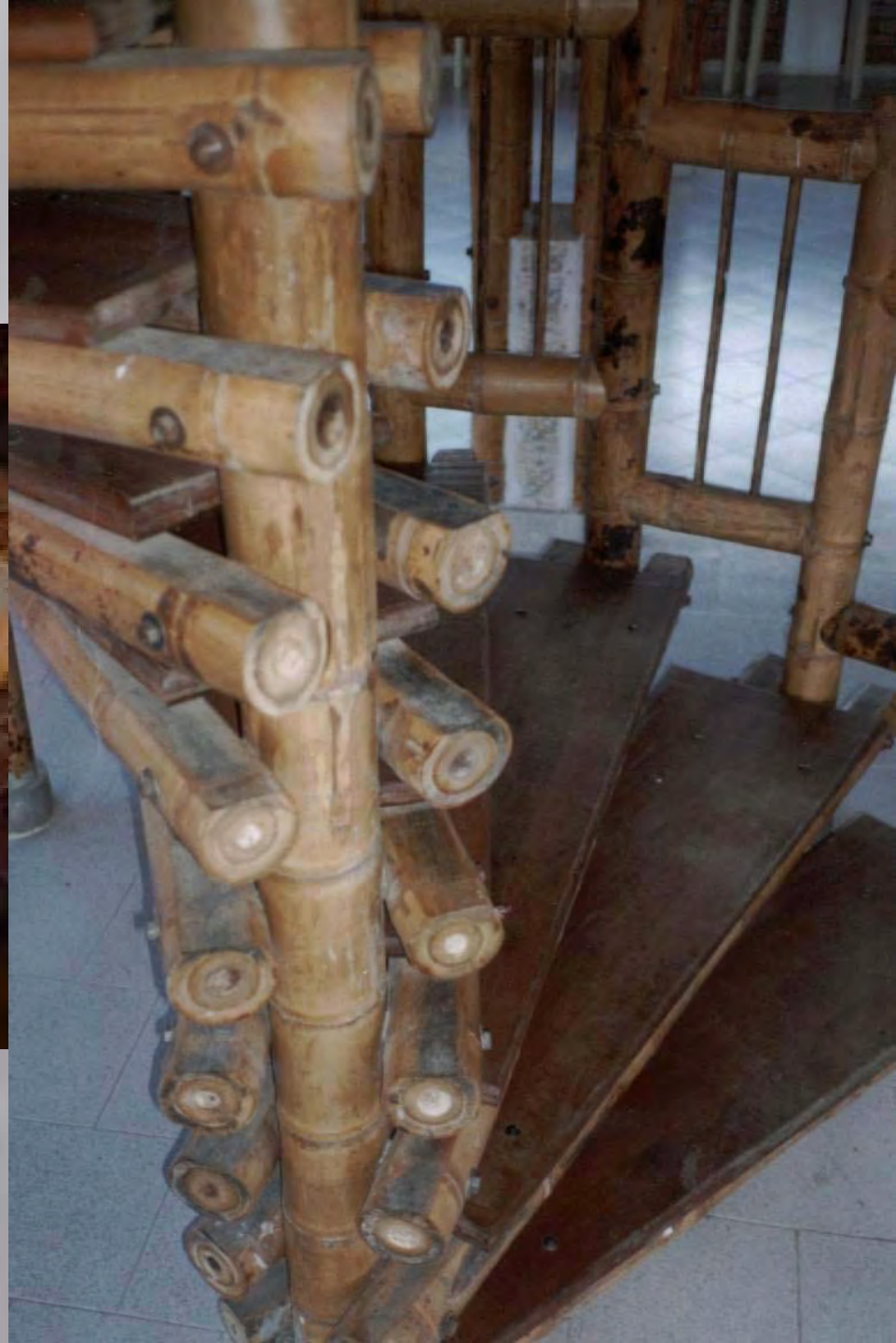



SEPARADOR
RETENEDOR
PASADOR
SOBRE
NUDO
CAÑUTOS CON
MORTERO
VARILLAS O
PLETINAS
BASE
METÁLICA
SEPARADOR
RETENEDOR
DADO DE HORMIGON

Designing joinery



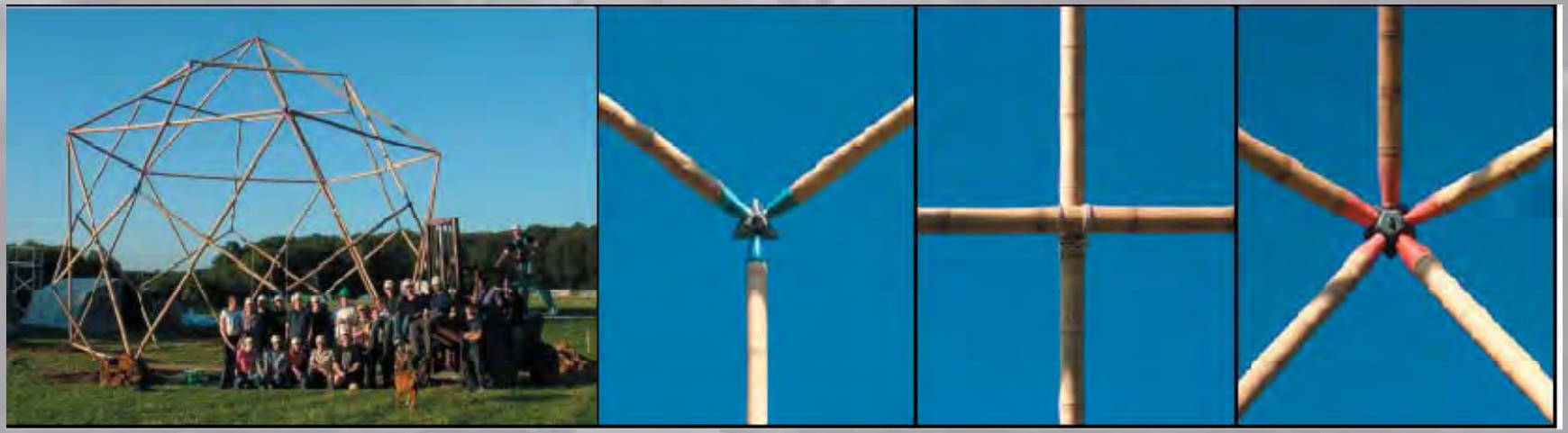

Nudo con cemento
Restaurante
"Al-Andalus"

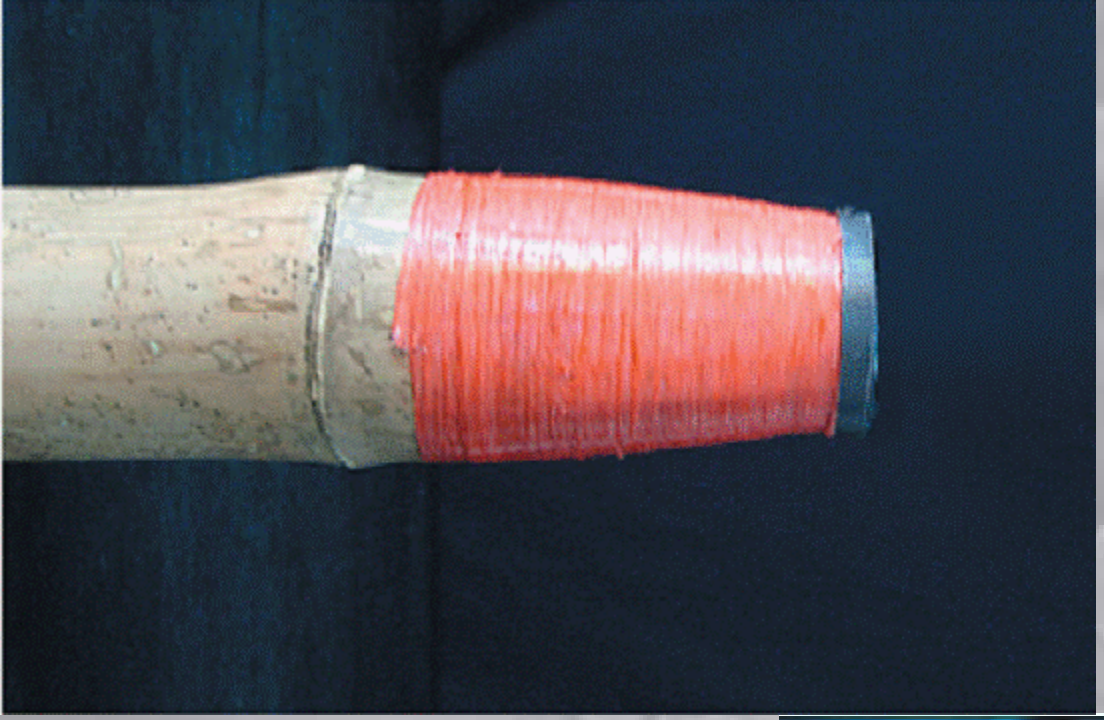


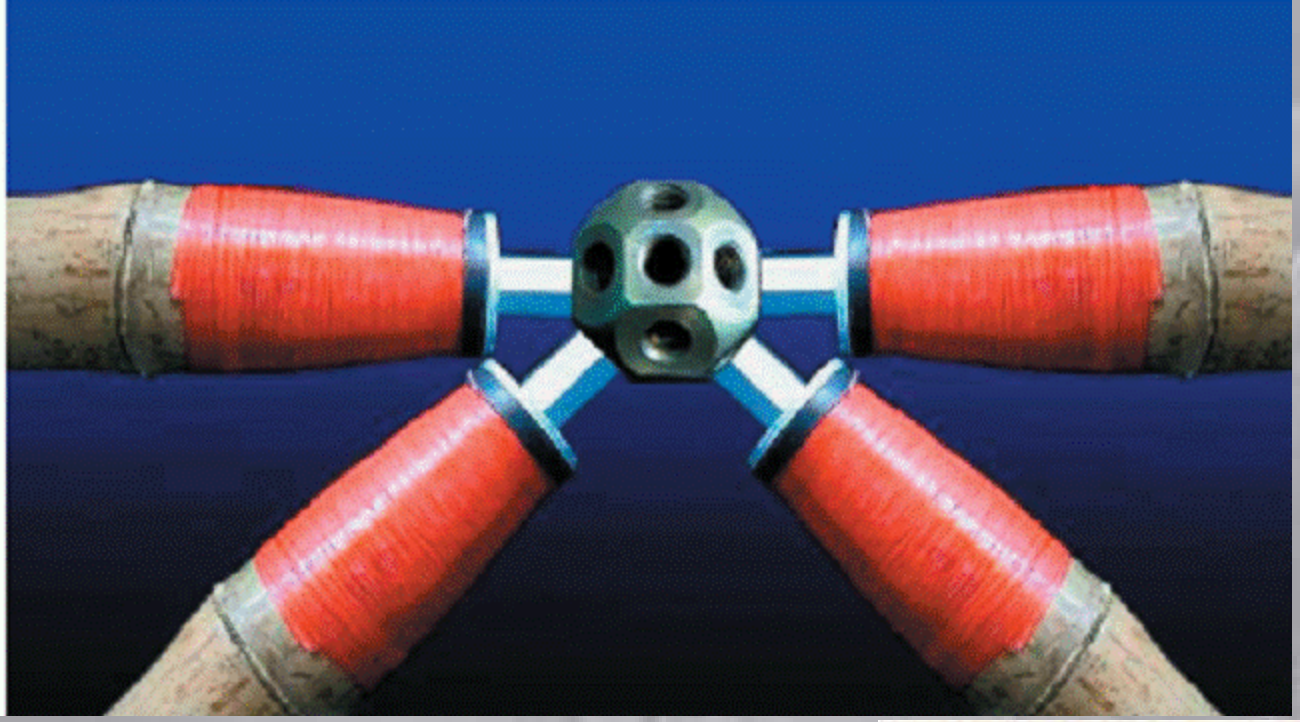
High-tech joints

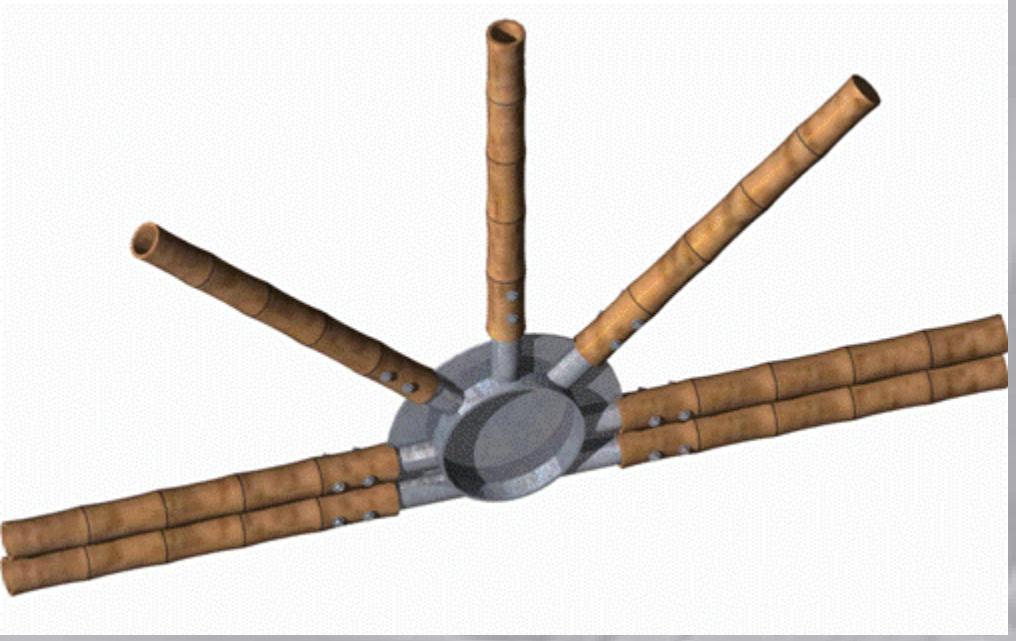
- An external element is used to join more that 2 bamboo culms

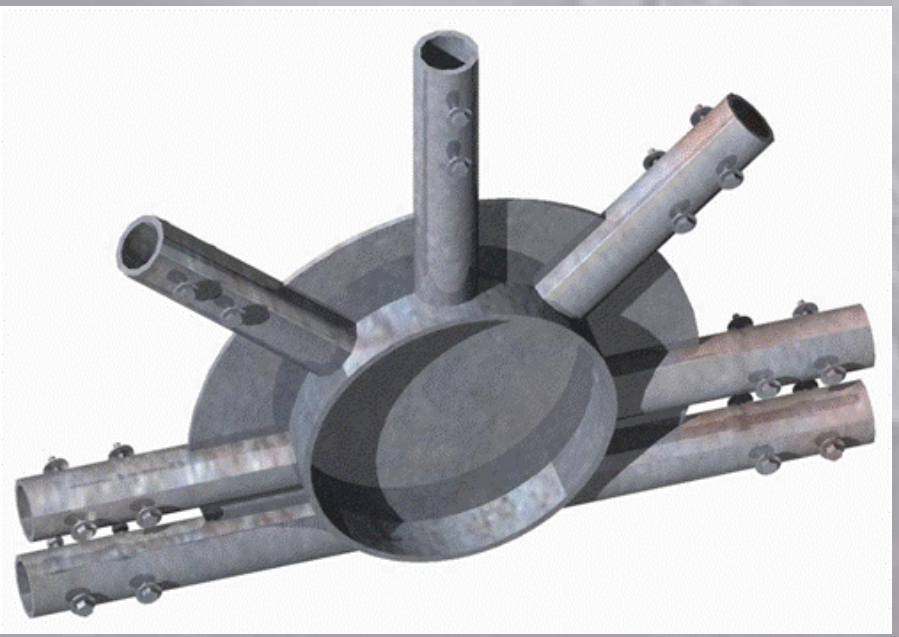
- Keep bamboo light
- Bear as much force as possible
- Easy to assemble and to dismantle
- Makes bamboo appropriate for modern designs

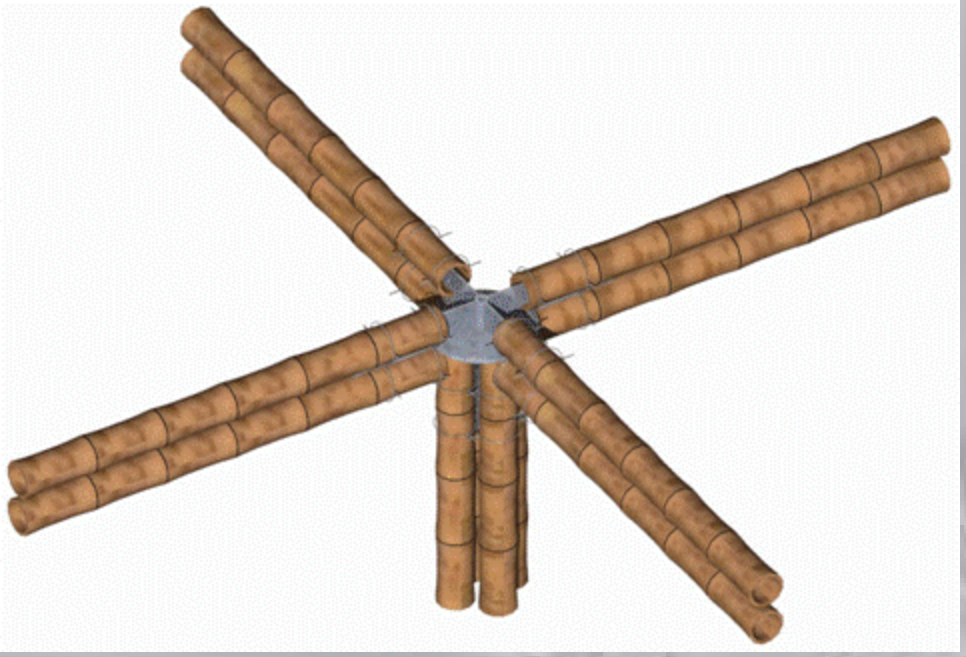


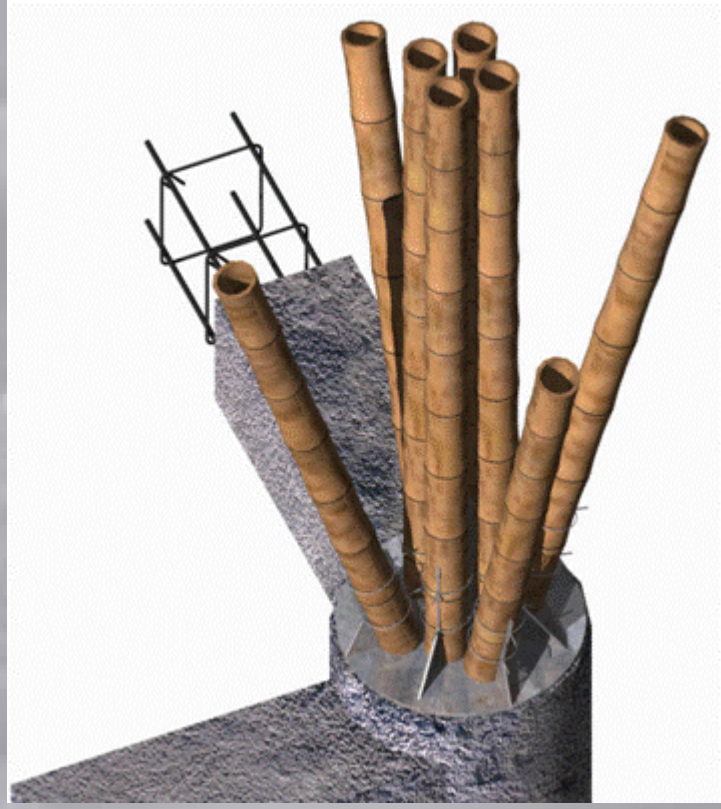


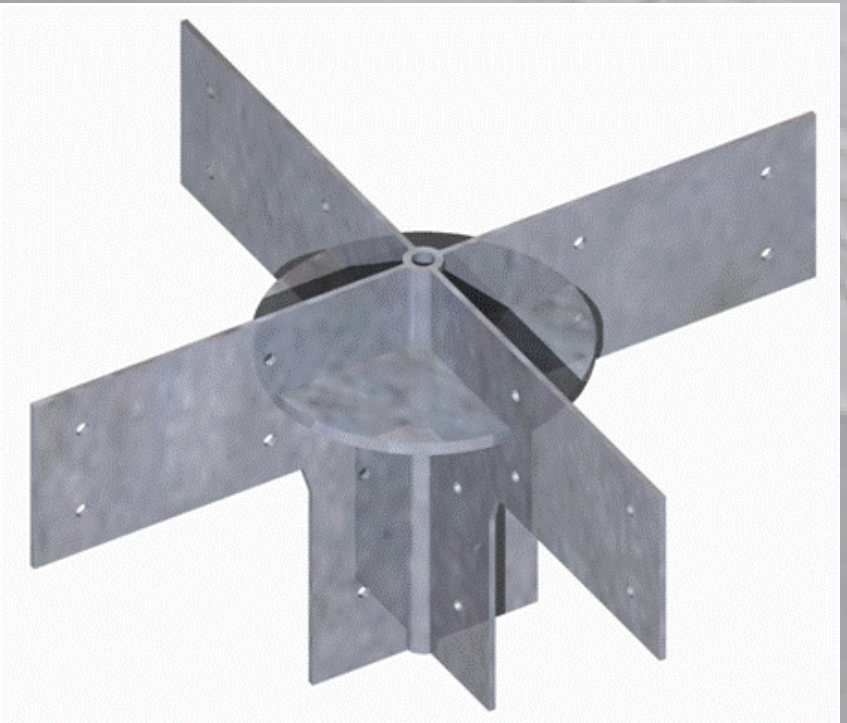












Thank you!!!

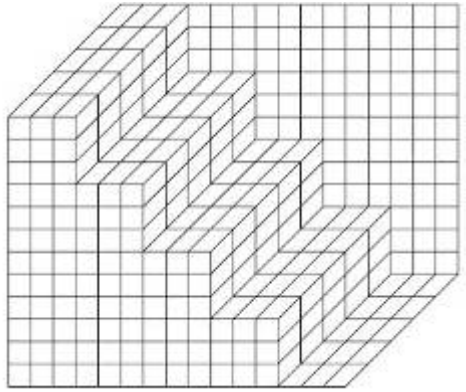
A4A Collaboration Thailand Bridge Shoots Event

Buro Happold Infrastructure
Kien Hoang
20th Oct 2007

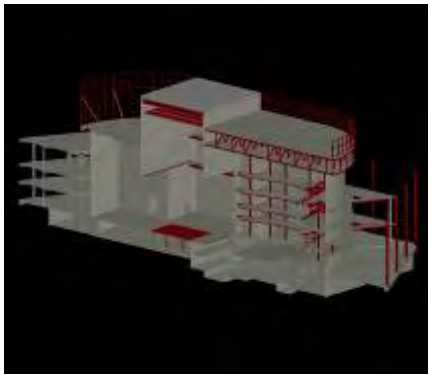
www.a-4-a.org

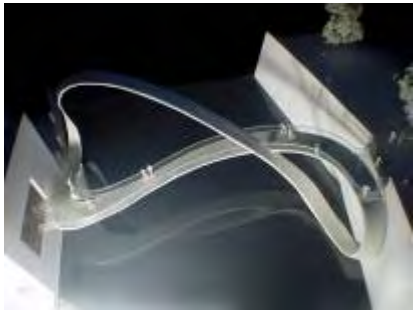
Buro Happold

Kien Hoang
MEng(Cantab) MIstructE CEng
Senior Bridge Engineer



About myself





About myself








The Project

Background: *location*

Background: *context*

Background: *client*

Background: *site*

Background: *site constraints*

Background: *precedent*

Background: *precedent*

Proposal: *brief*

- **Total length:** **>80m (to suit)**
- **Loading:** **pedestrian + small scooter**
- **Construction:** **local semi-skilled labour**
- **Programme:** **completion by July 08**
- **Budget:** **$10,000 approx**

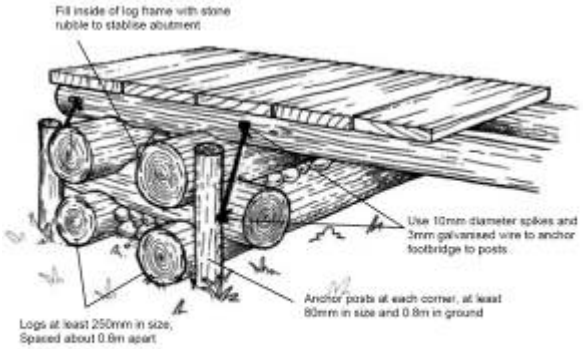
Proposal: *overview*

Challenges:

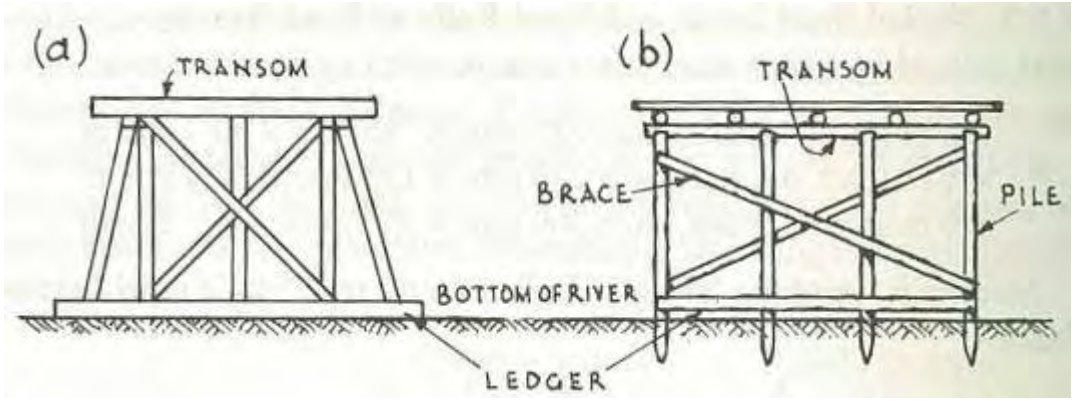
- Site constraints
- Resources
- Construction
- Engineering
- ‘Sustainability’

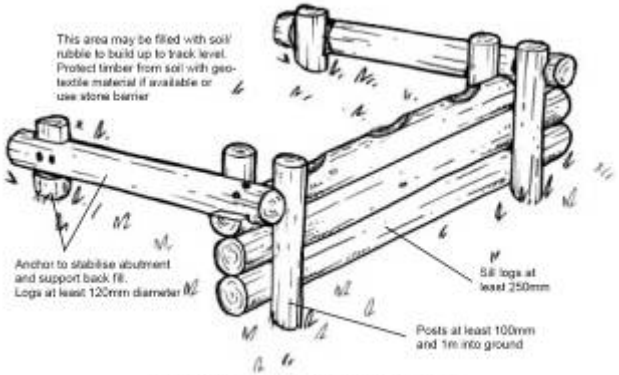
two spans or not two spans…

Proposal: ***substructure***

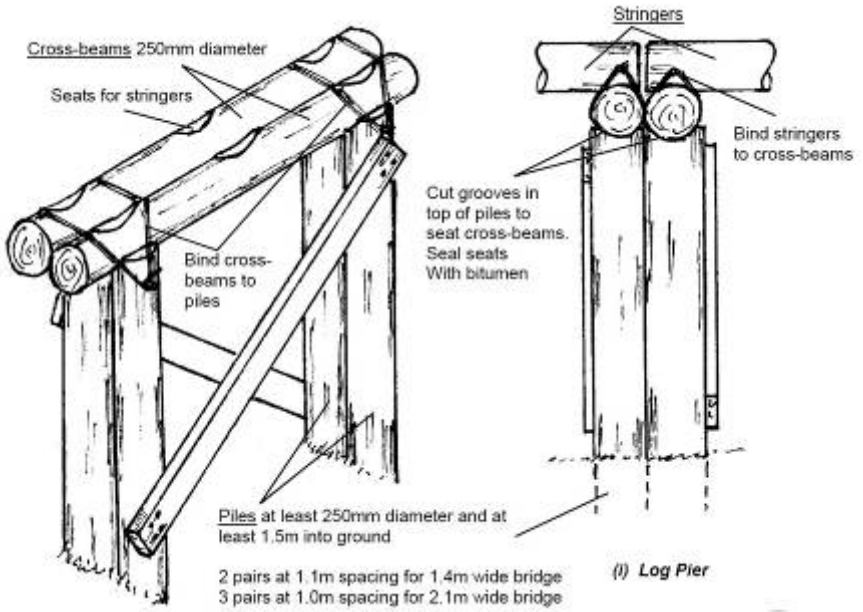


(i) Log Crib Abutment - suitable for fairly flat stable bank. If necessary excavate base for crib. Seat logs on a stone bed





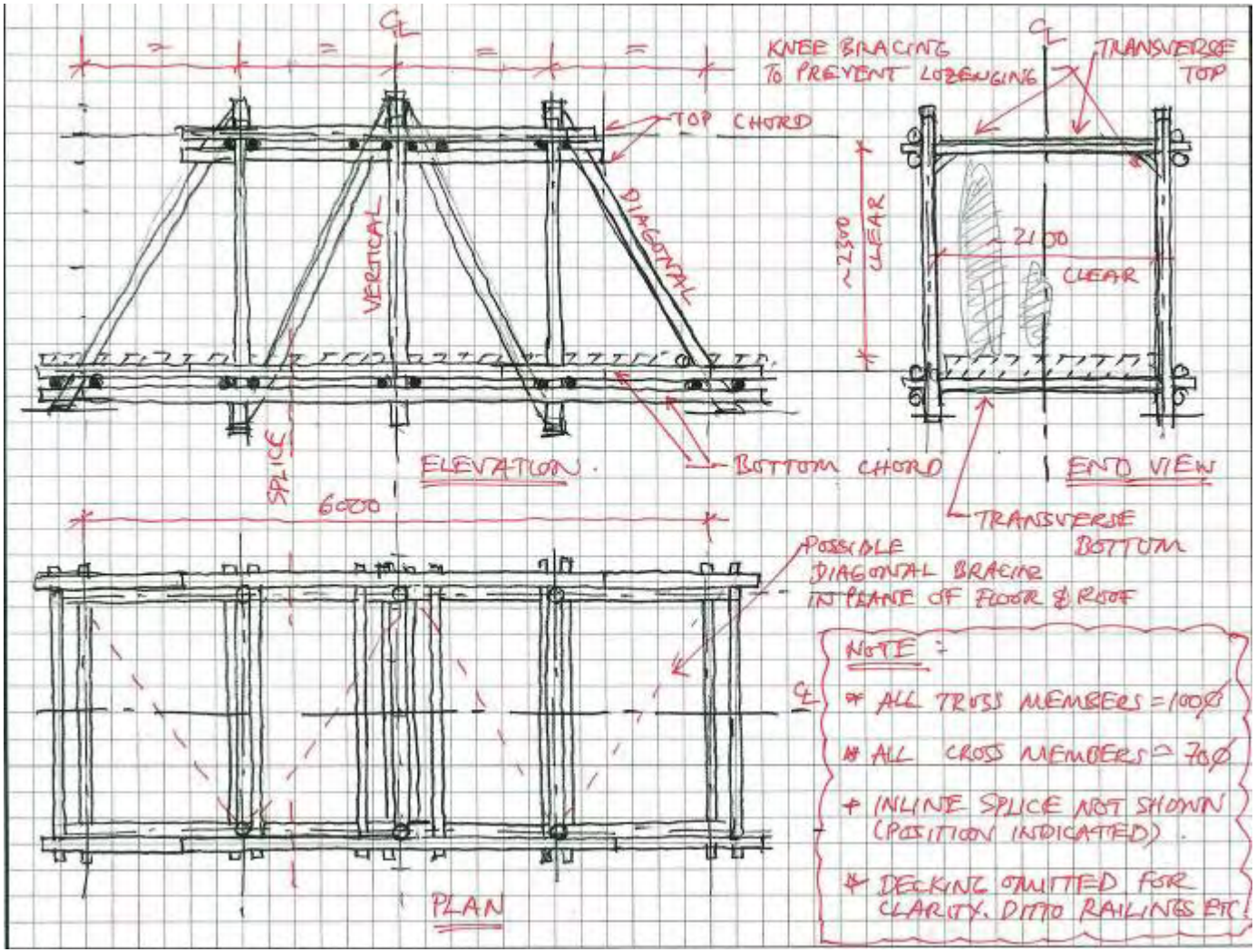
(ii) Log Abutment - suitable for medium slope bank



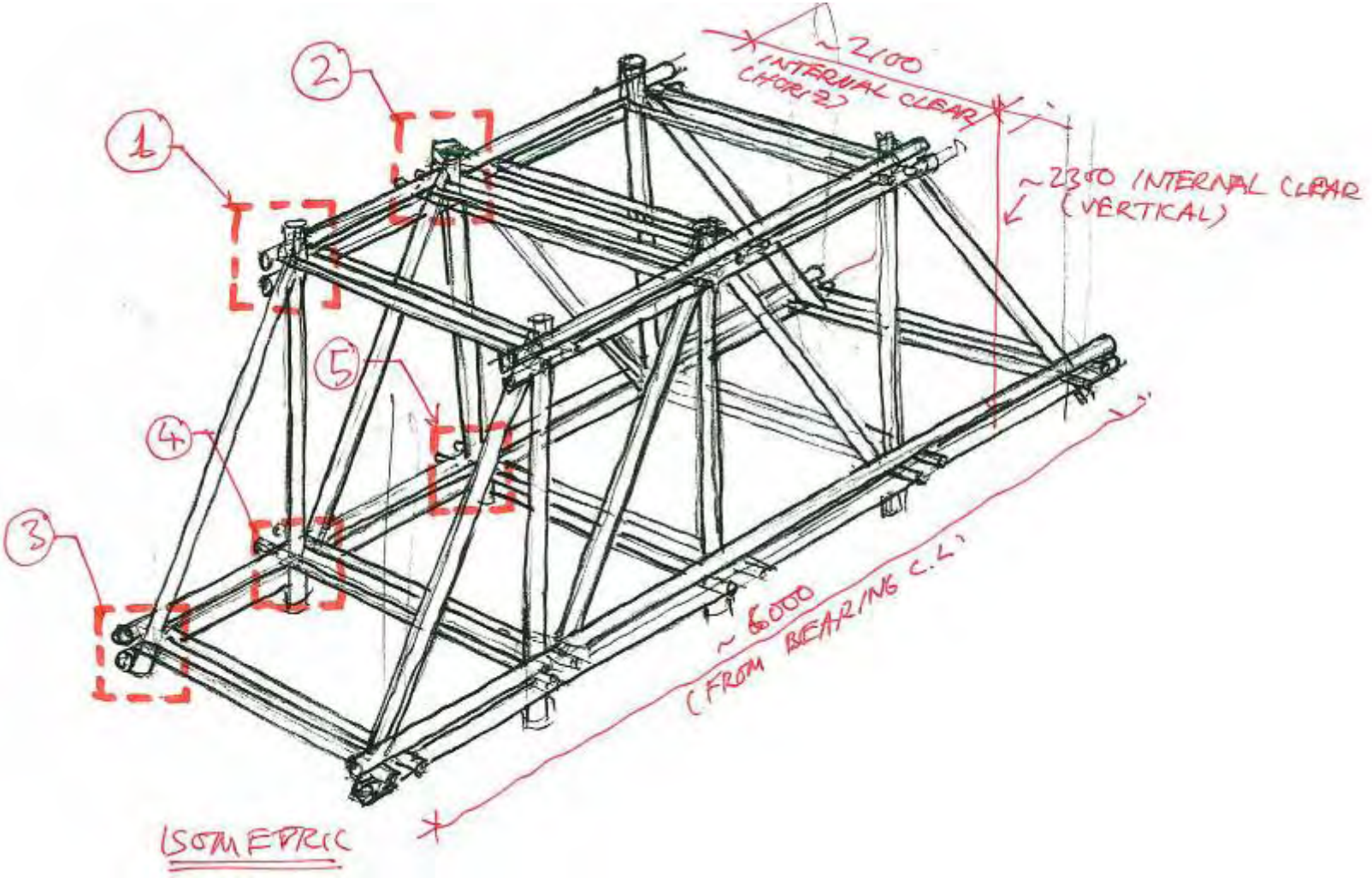
(i) Log Pier

Proposal: ***substructure***

Proposal: *superstructure - form*



Proposal: *superstructure - form*

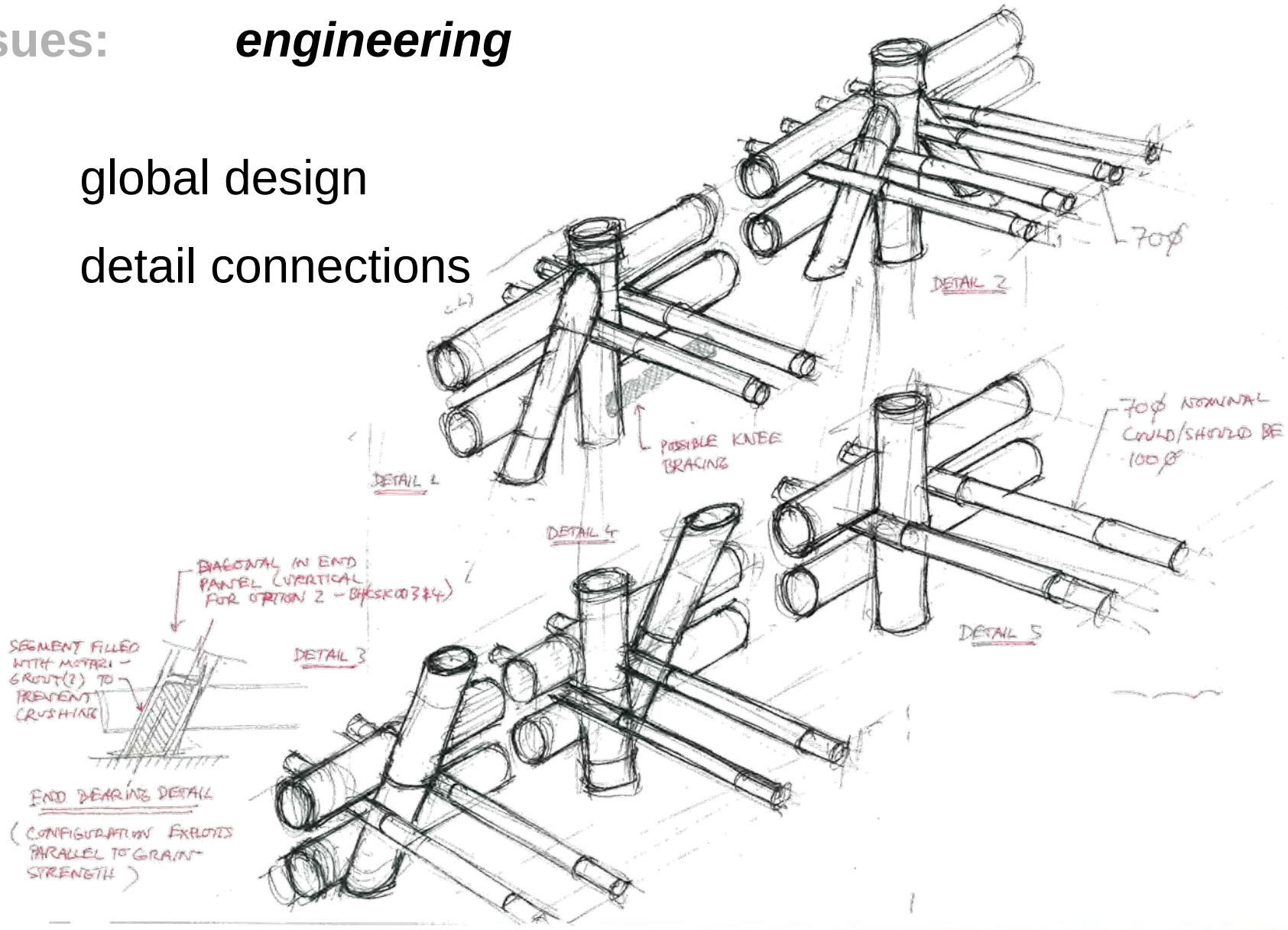


Issues: *site specific “environmental” drivers*

- flood loading
- scour
- river course

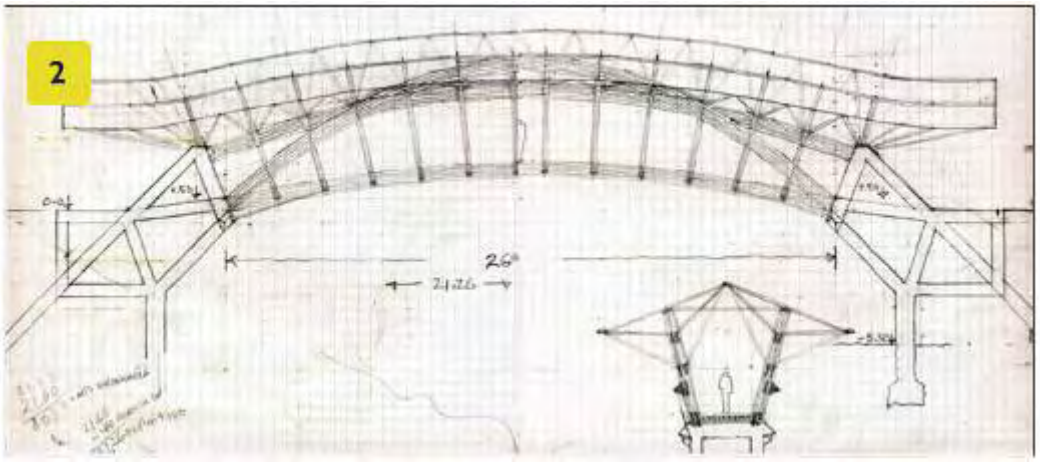
Issues: *engineering*

- global design
- detail connections



Issues: *engineering*

Issues: *engineering*



Issues: *construction & erection*

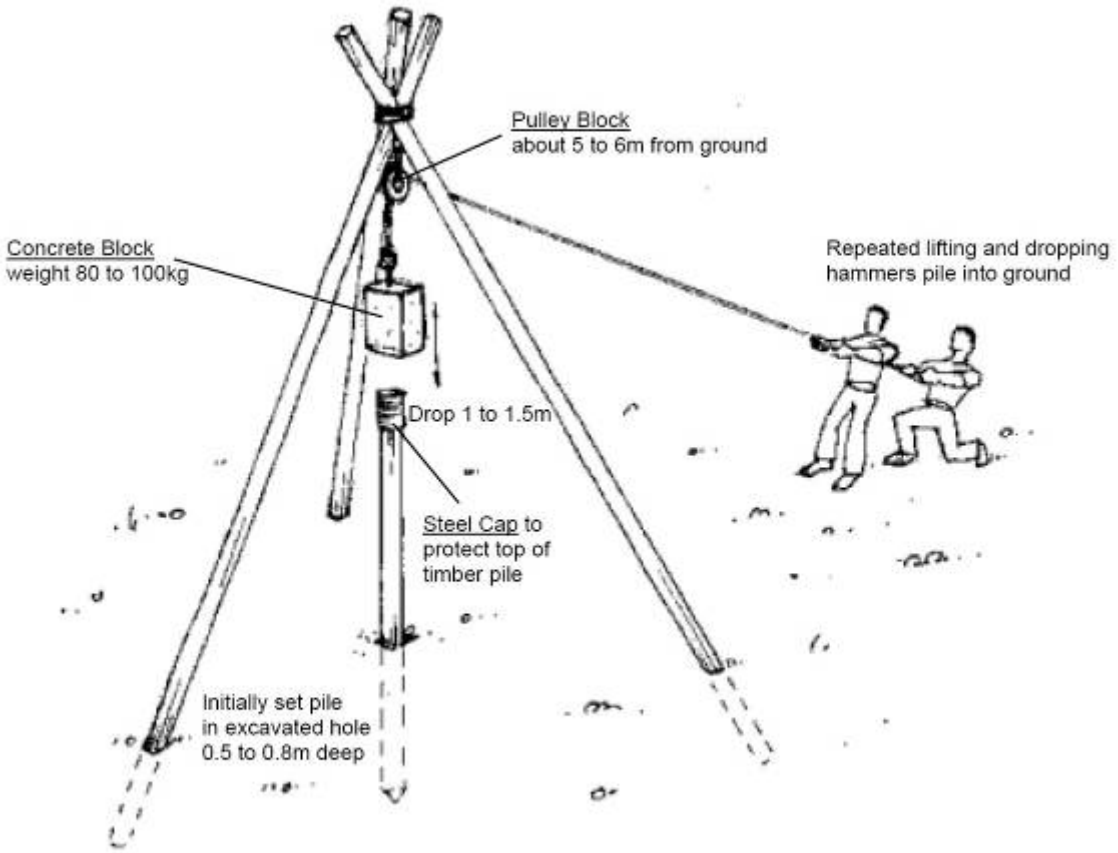
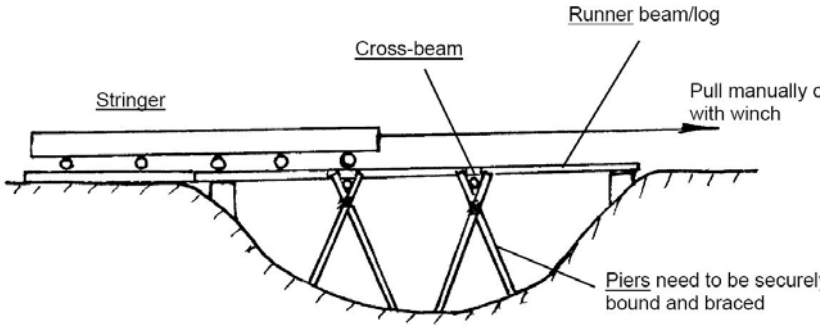


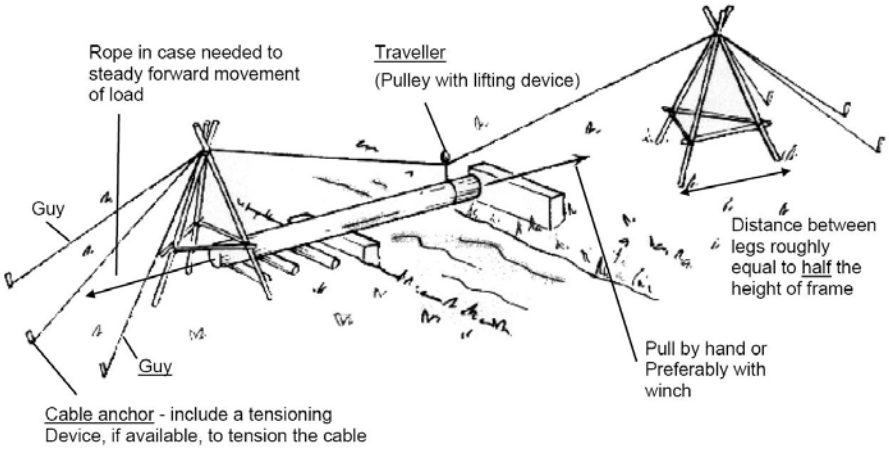
Figure 7.9: Sinking of Piles into Ground

Issues: *construction & erection*

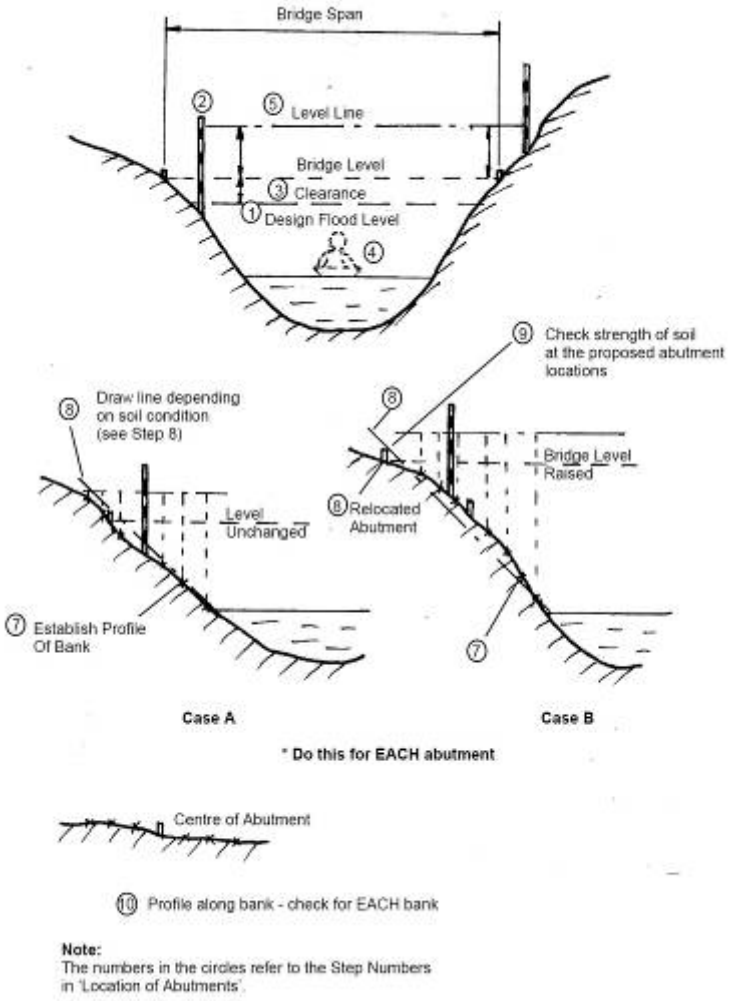
Issues: *construction & erection*



Erect temporary piers with cross beams to support runners (logs/beams) on which stringer can be pulled across gap



Issues: *site survey & setout*



Further investigations

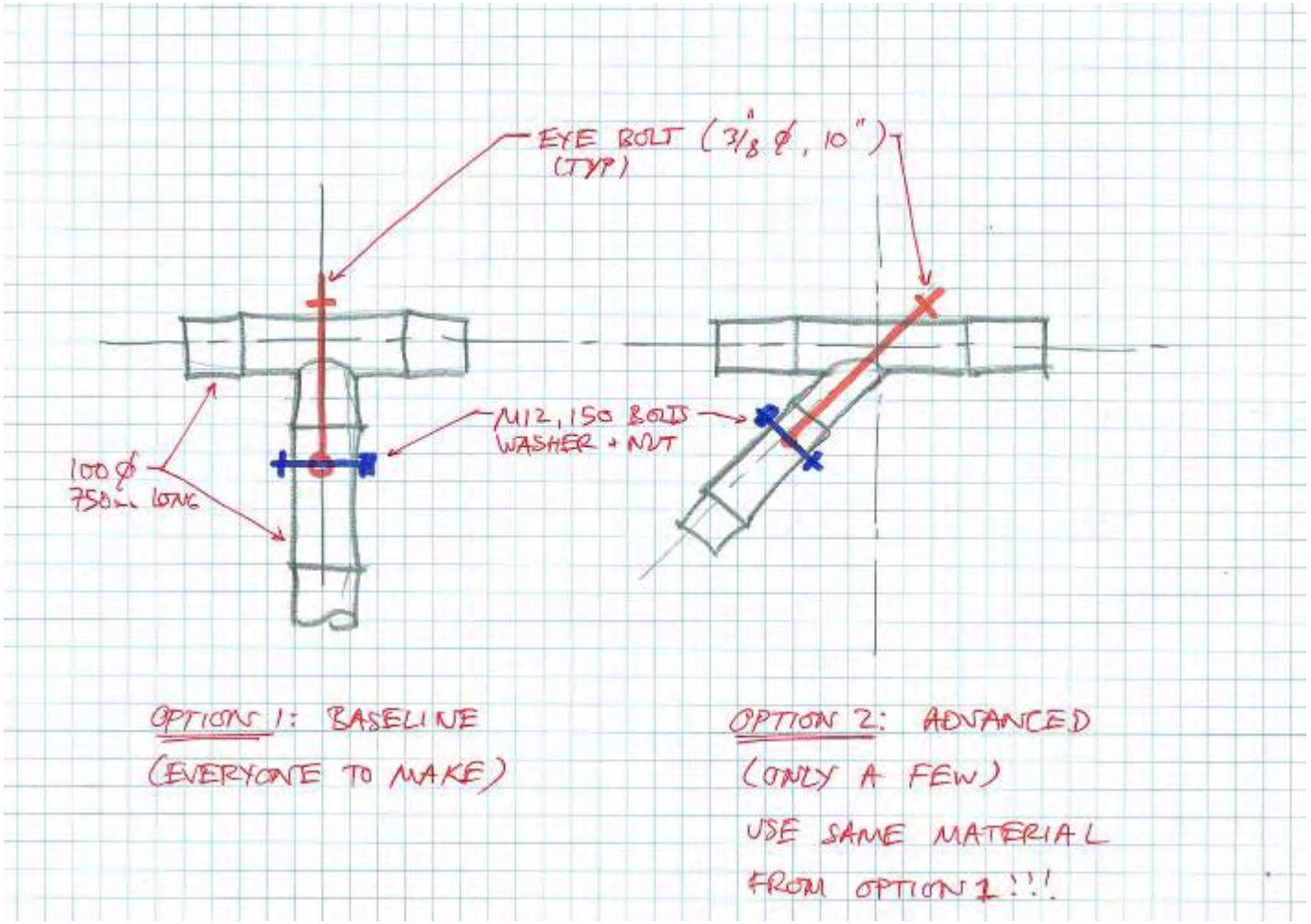
- **Shoots event**
- **calculations**
- **weekend in Wales**

Programme

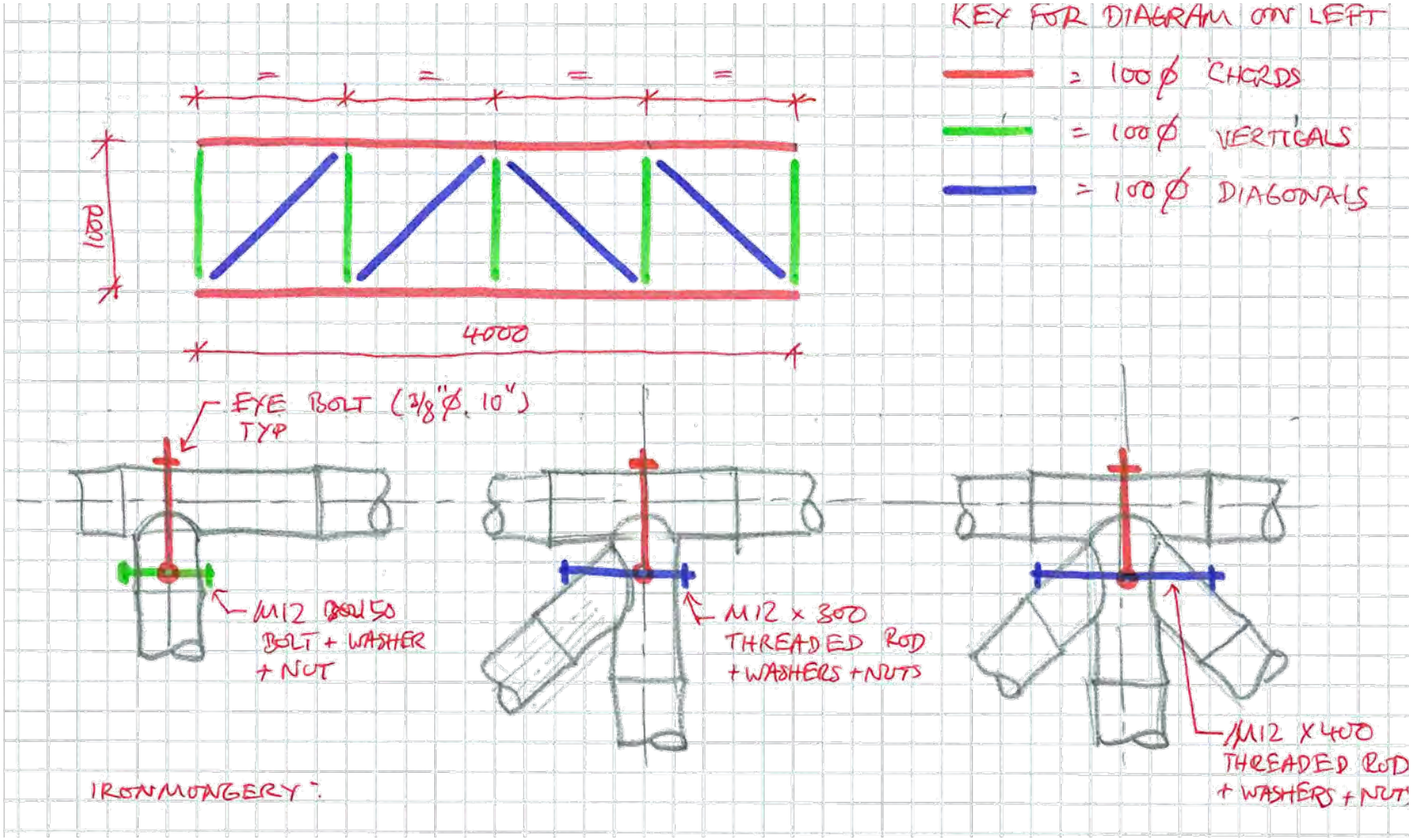
Nov/Dec ’07:	**site setup, substructure construction**
	bamboo harvest & treatment
Jan/Feb ’08	**superstructure construction**
Summer ’08	**fingers crossed!**

Shoots

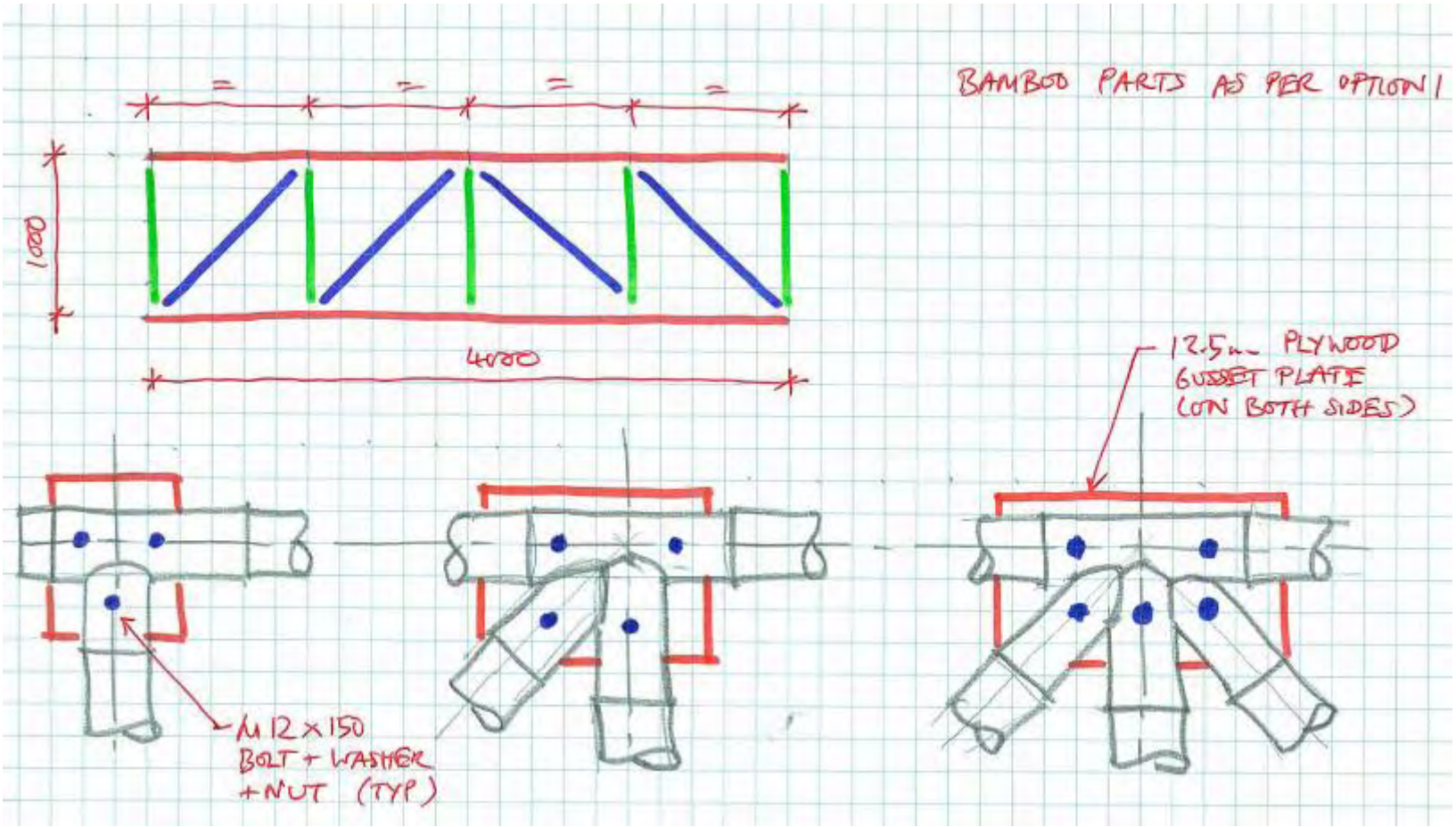
Individual exercise



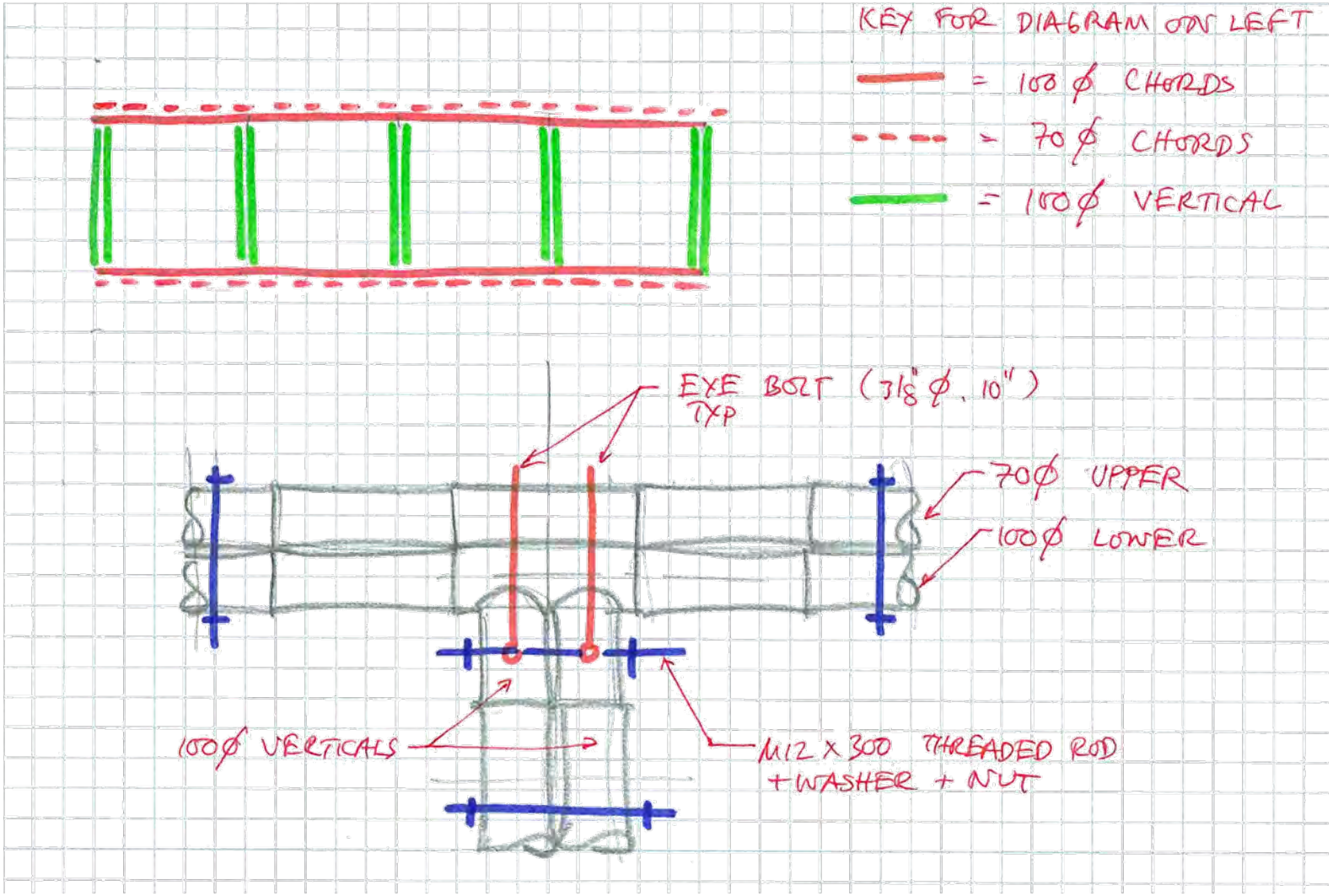
Prototype 1: truss with rod connections



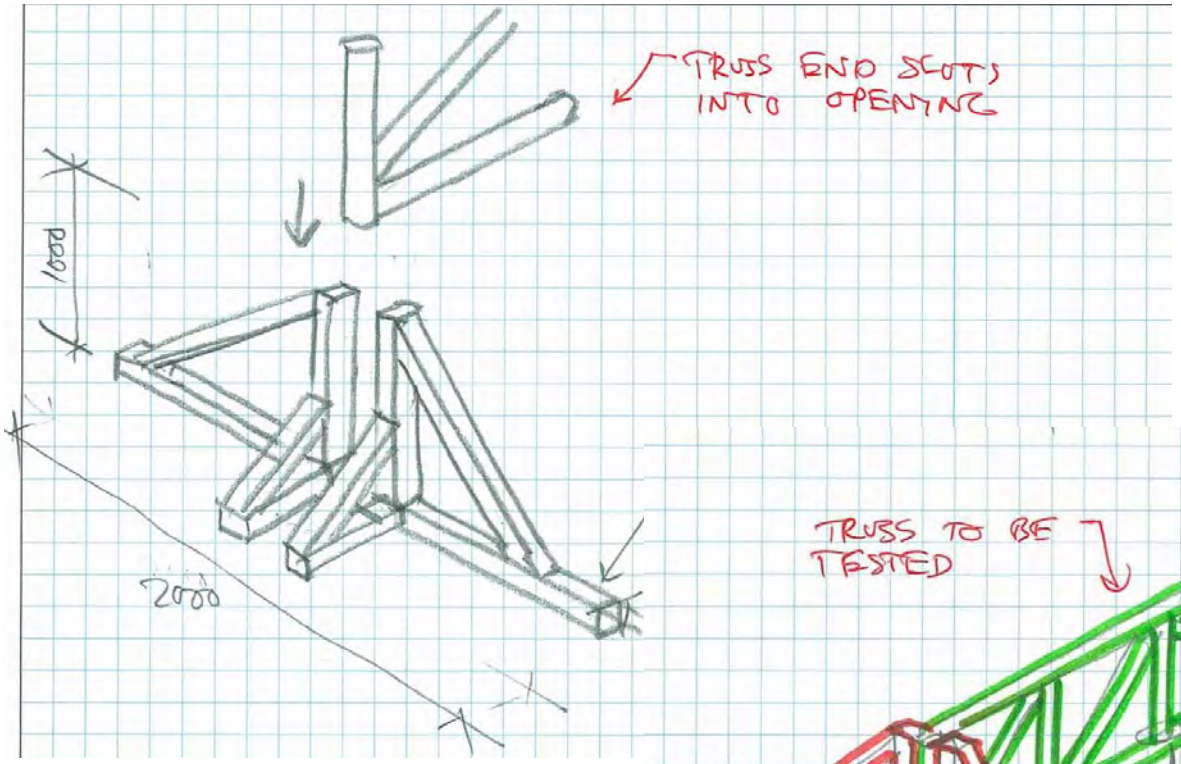
Prototype 2: truss with gusseted connections

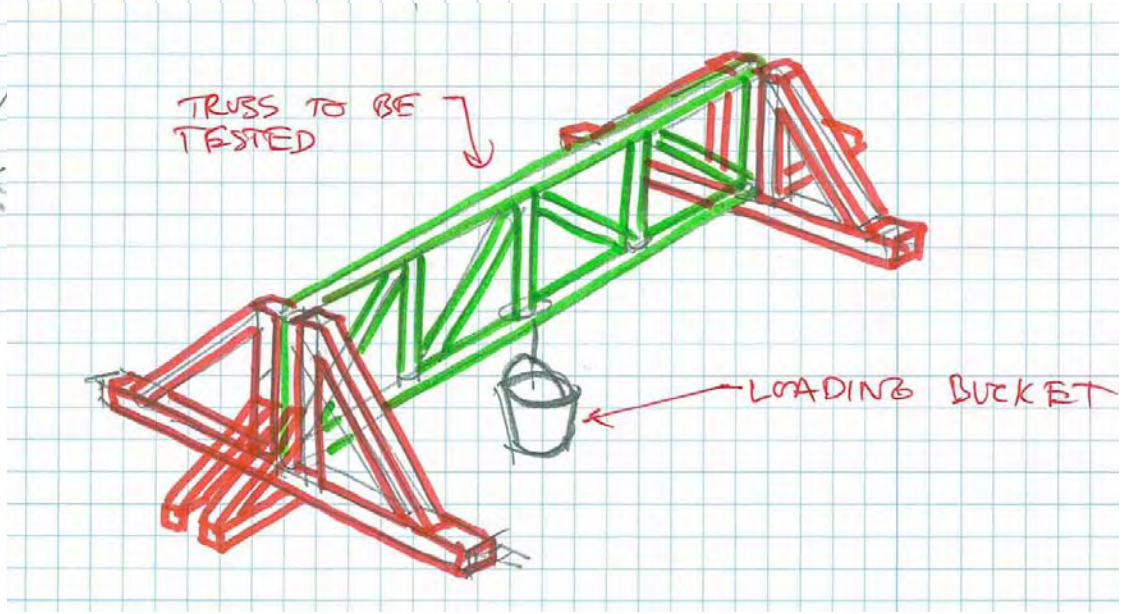


Prototype 3: Vierendeel truss



Testing


TRUSS END SLOTS INTO OPENING
1000
2000


TRUSS TO BE TESTED
LOADING BUCKET

Examples

Examples

Enjoy!

(but please take care)