MANUAL FOR POST-EARTHQUAKE REBUILDING IN NEPALESE VALLEYS

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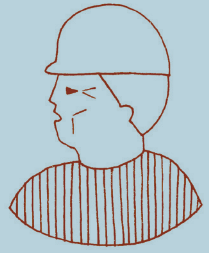
ASSOCIATION FRANCAISE DU GENIE PARASISMIQUE
FRENCH ASSOCIATION FOR EARTHQUAKE ENGINEERING

“Earthquakes don’t kill people... Improperly design buildings do !”



When the shaking from the Himalayan earthquake occurred just before noon on April 25, most of the victims were within buildings hastily constructed and poorly built.

This earthquake may have caught Nepal by off guard, but that doesn’t mean it came as a surprise. In fact Nepal is located on a well-known tectonic plate boundary where Indian Plate goes beneath Asia forming the Himalayan mountain range. This plate collision gives raise to frequent earthquakes, some of them being particularly strong with return period of few centuries.

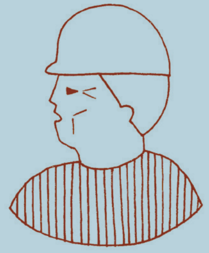
And the resulting devastation came as no surprise, because buildings in cities and in villages of high Nepalese valleys are not constructed to stand up to a quake.

Since it’s impossible to predict an earthquake with reliability, the most efficient preventive action is to (re) build with earthquake-resistant principles.

This pedagogic document, prepared by the French Association for Earthquake Engineering, aims at applying these simple but efficient earthquake resistant principles to one storey traditional houses in Nepalese valley villages using available materials at those isolated places.

Thierry WINTER and colleagues who worked on this guide

SUMMARY



1

Why buildings collapse during an earthquake?

2

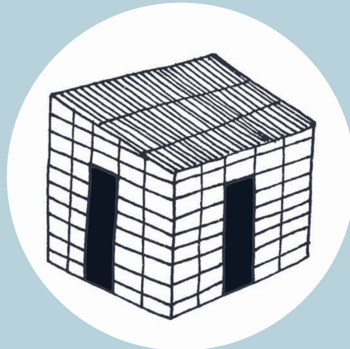
Well implant buildings

3

Well design buildings

4

(Re)build earthquake-resistant traditional buildings

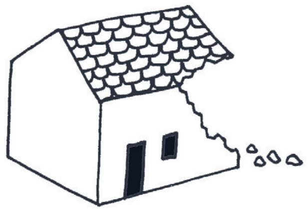


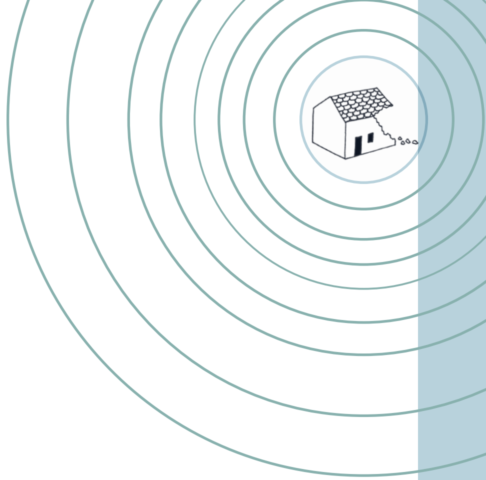
5

Build earthquake-resistant bag-buildings

1

Why buildings collapse during an earthquake?





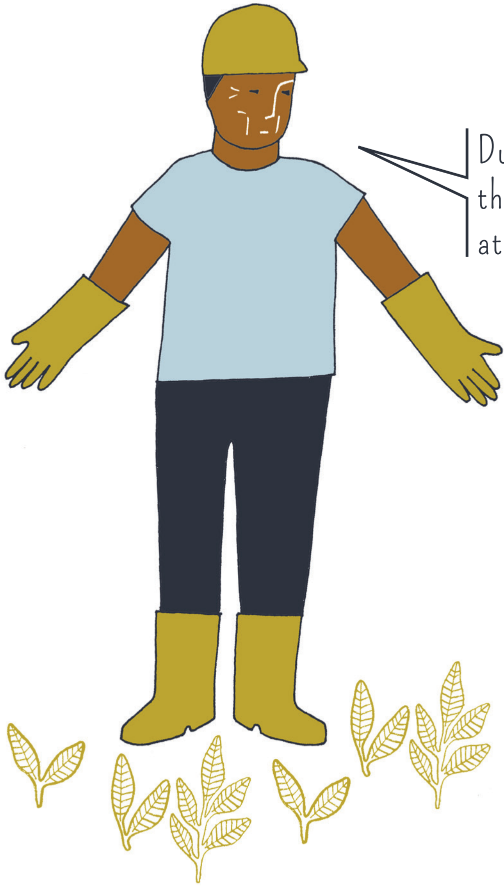
Effects of earthquake on masonry buildings

(bricks, rubble stones)

BEFORE QUAKE

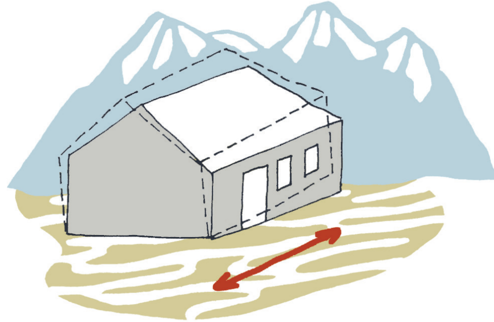
DURING QUAKE

AFTER QUAKE

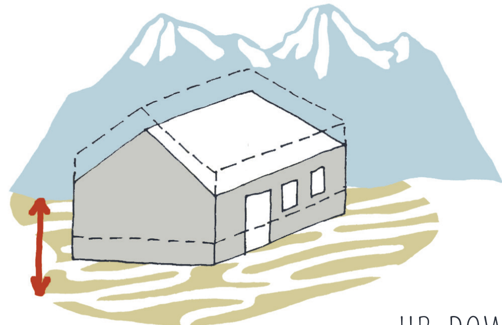


During an earthquake,
the building is shaking
at its bottom in all directions.

FORE-BACK

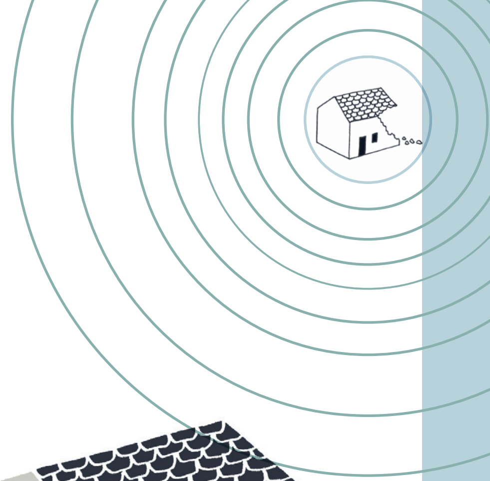


LEFT-RIGHT

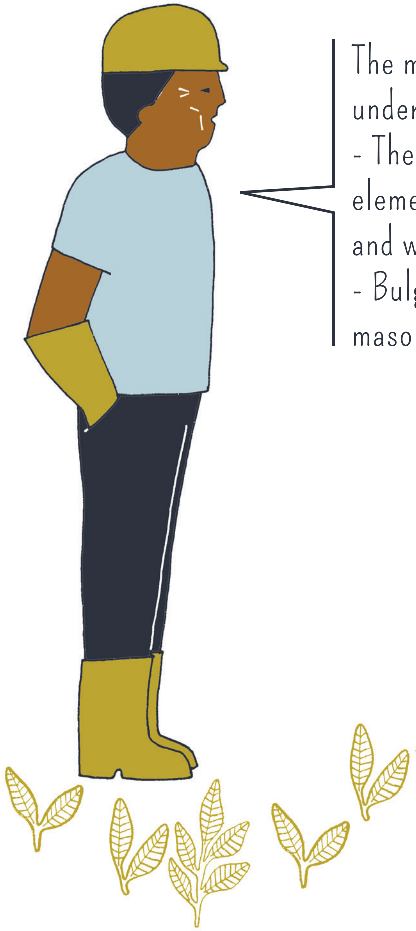


UP-DOWN

Effects of earthquake on masonry buildings (bricks, rubble stones)



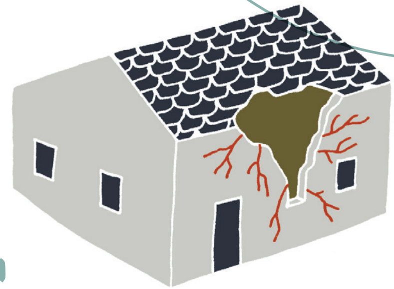
If the walls are not connected at their own junctions and with the roof, cracks appears at the junctions and the walls could collapse under earthquake.



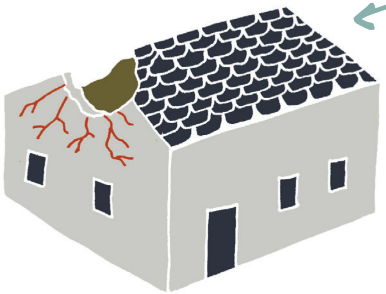
The main damages of masonry buildings under earthquake are in particular :
- The failure of the junctions between wall elements with the separation's walls and walls at the corner of masonry buildings
- Bulging delamination and collapse of stone masonry buildings.

Total collapse

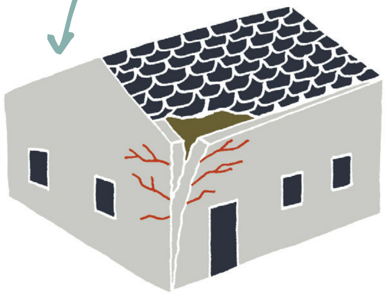
Stone wall delamination with buckled walls



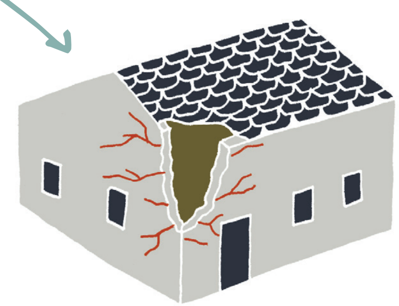
Collapse of large part of wall in the middle long walls or delamination (No lateral connections)



Gable collapse (no reinforcement vertical and horizontal band between walls)

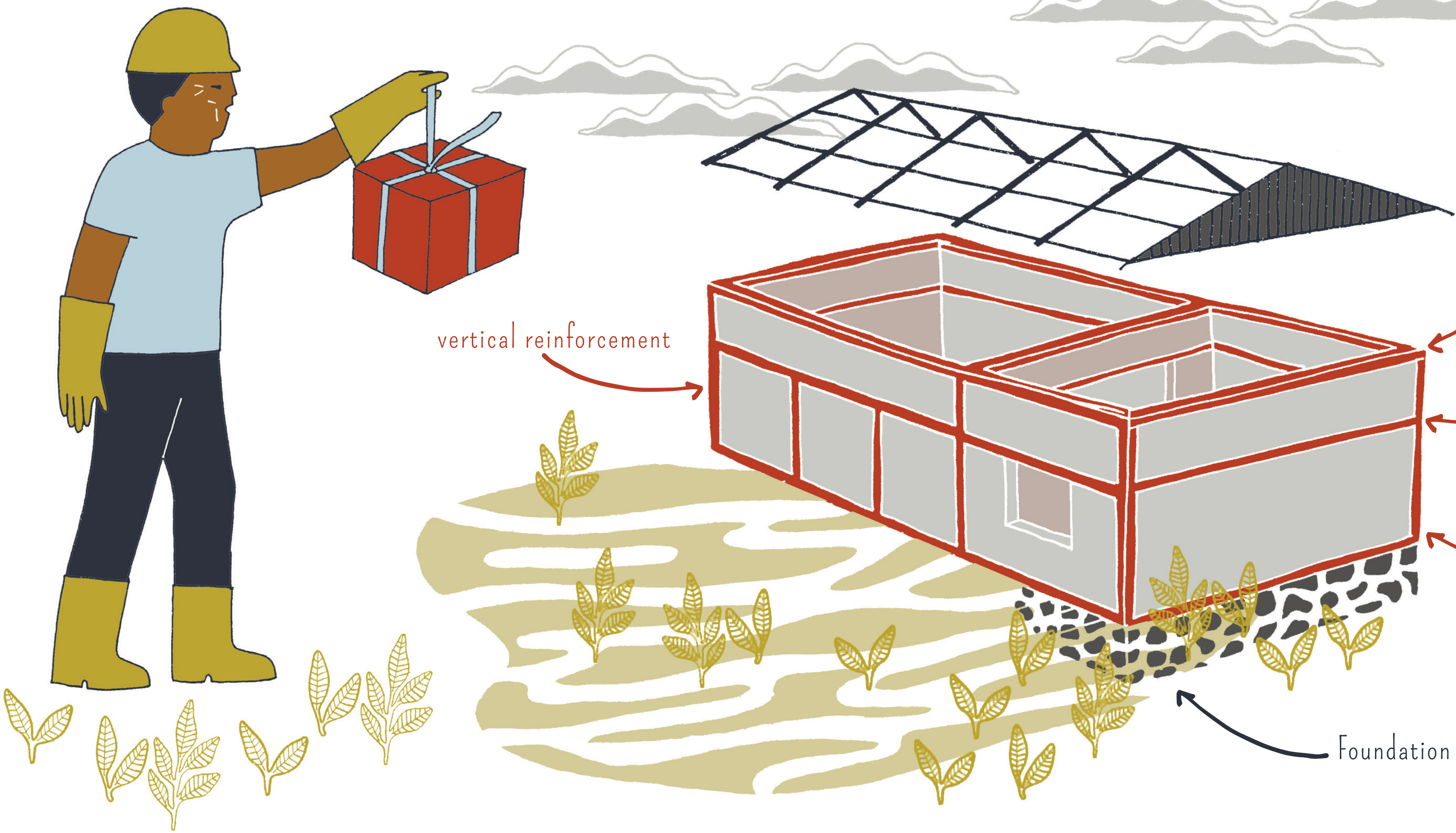


Walls going out of plumb (bad connection between roof and walls)



Collapse of corner (no reinforcement band between walls)

For a good seismic behavior and avoid the collapse, make a monolith building as a gift package



Essential internal elements
in buildings for earthquake safety

2

Well implant buildings

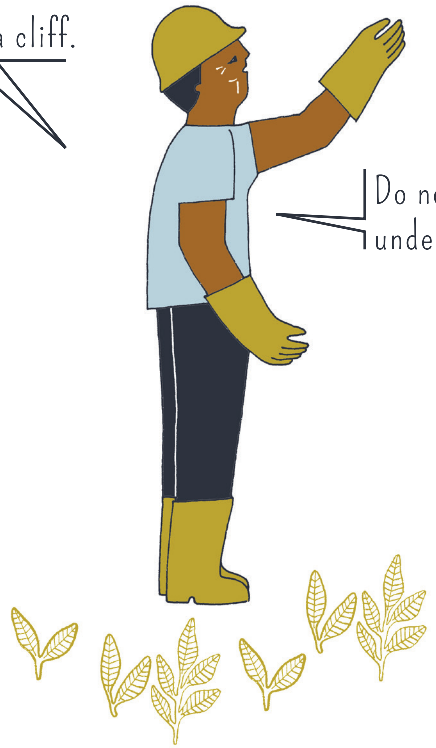
Don't do it !

NO !

NO !

Do not build at the edge of a cliff or close to a river/stream.

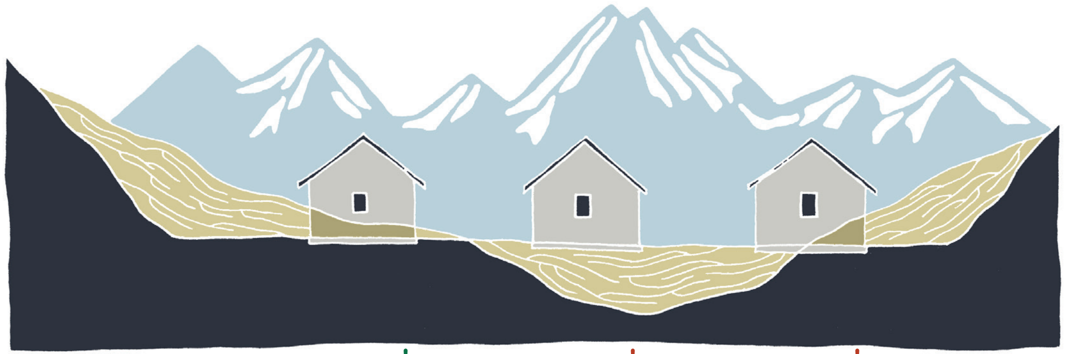
Do not build under a cliff.



Do not build under rocky blocks.

NO !

Do it !

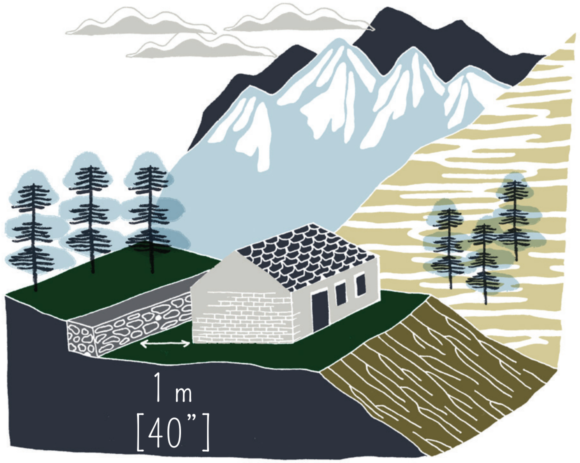


YES !   NO !   NO !

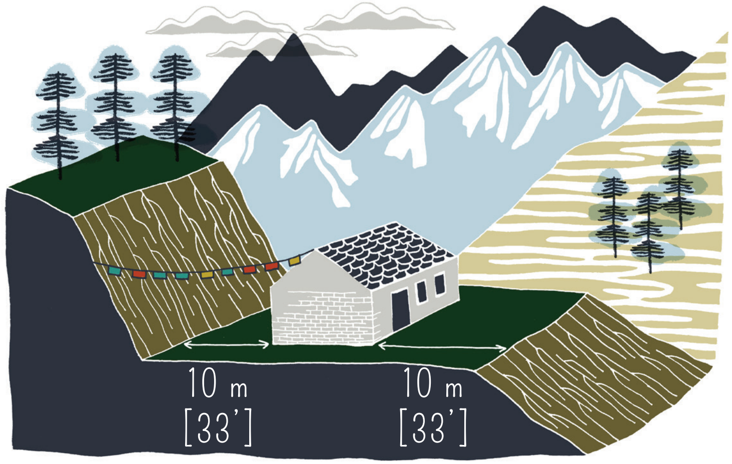
Foundation of buildings must be in firm soil.

Loose fill slopes must be stabilized.

Keep distances from landslide and rock fall hazard.



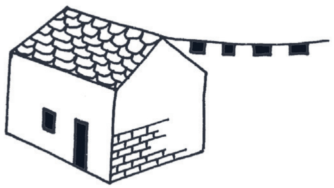
YES !



YES !

3

Well design buildings



Well design buildings

NO ! NO ! NO !

No irregular shapes.

Do not stack buildings.

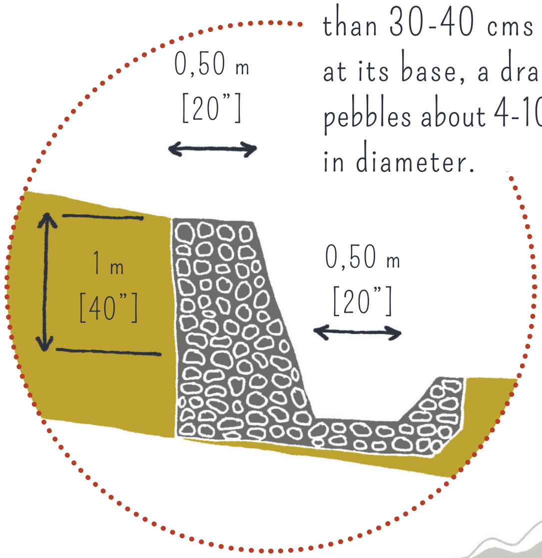
NO !

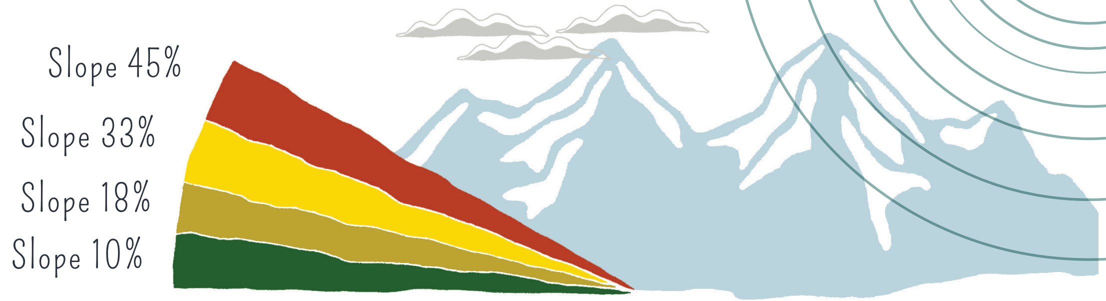
No piles for accommodating slope.

NO !

Preparation of horizontal platforms

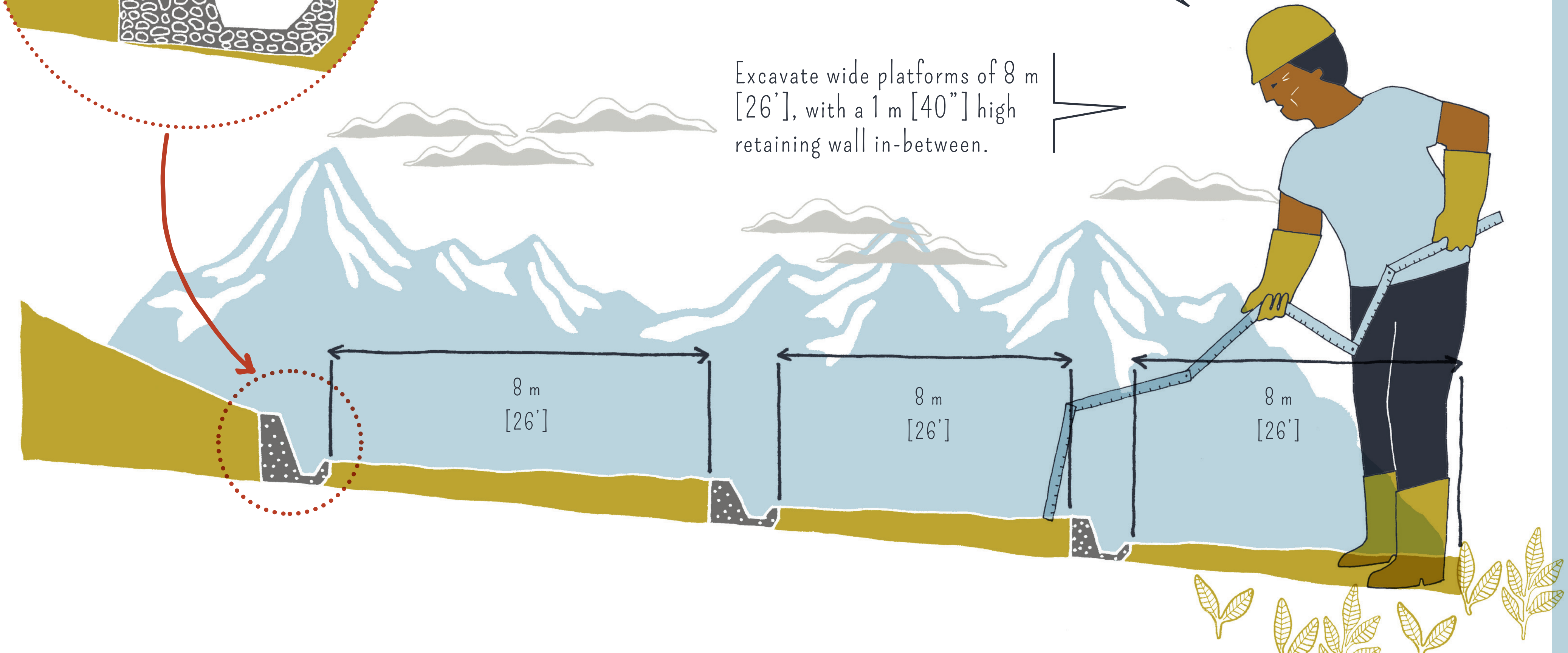
Retaining wall, about 1 m [40”] height and 50 cms [20”] thick, made of rocky blocks greater than 30-40 cms [12-16”], with, at its base, a draining ditch made of pebbles about 4-10 cm [2-4”] in diameter.





Slopes greater than 33% are forbidden. Prefer slopes lower than 18% (1 to 3), maximum handmade slope.

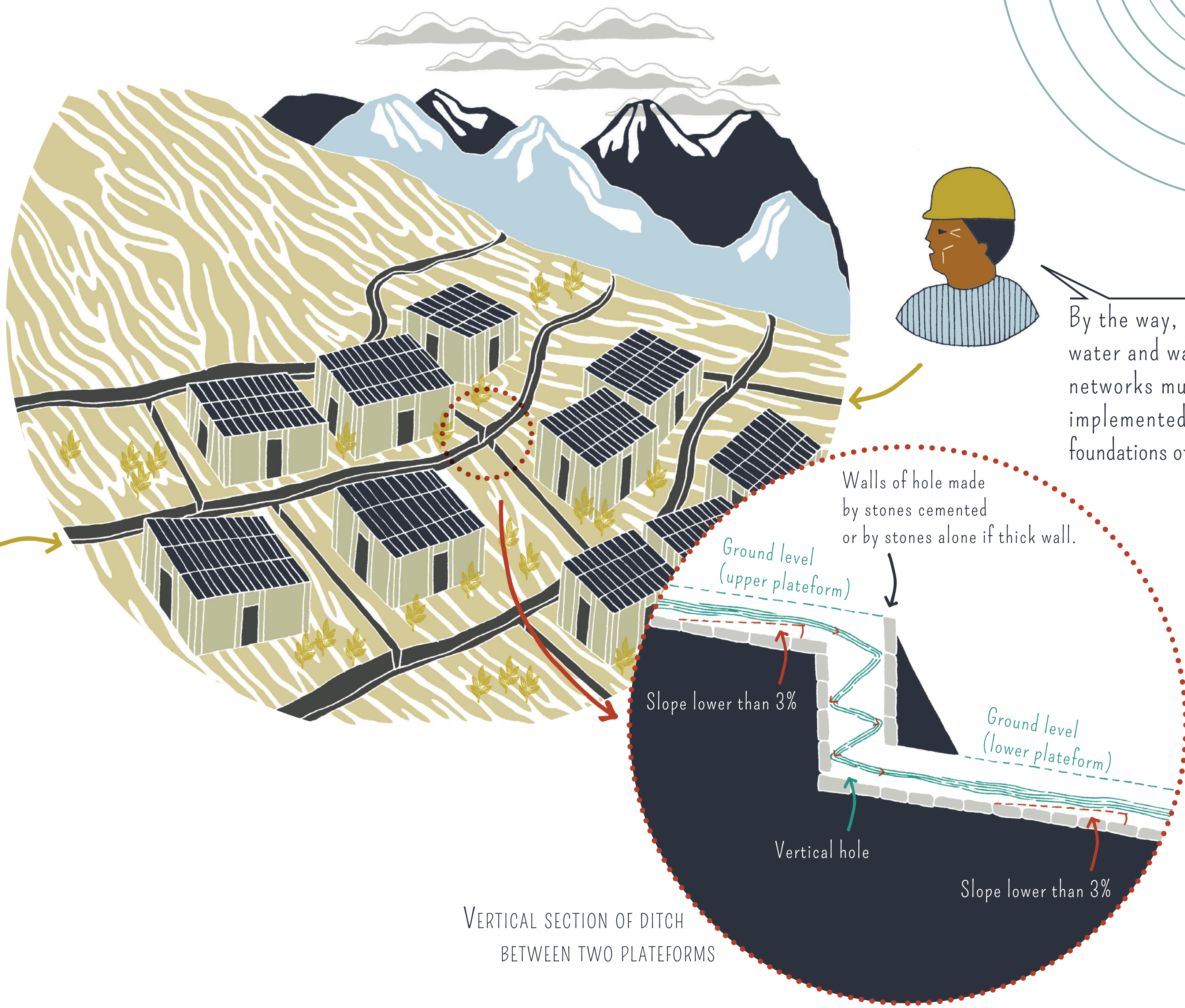
Excavate wide platforms of 8 m [26’], with a 1 m [40”] high retaining wall in-between.



Evacuation of rainwaters

Platform organization has to take into account run off water evacuation through a dedicated ditches network.

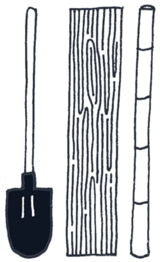
By the way, drinking water and wastewater networks must be also implemented far from foundations of buildings .



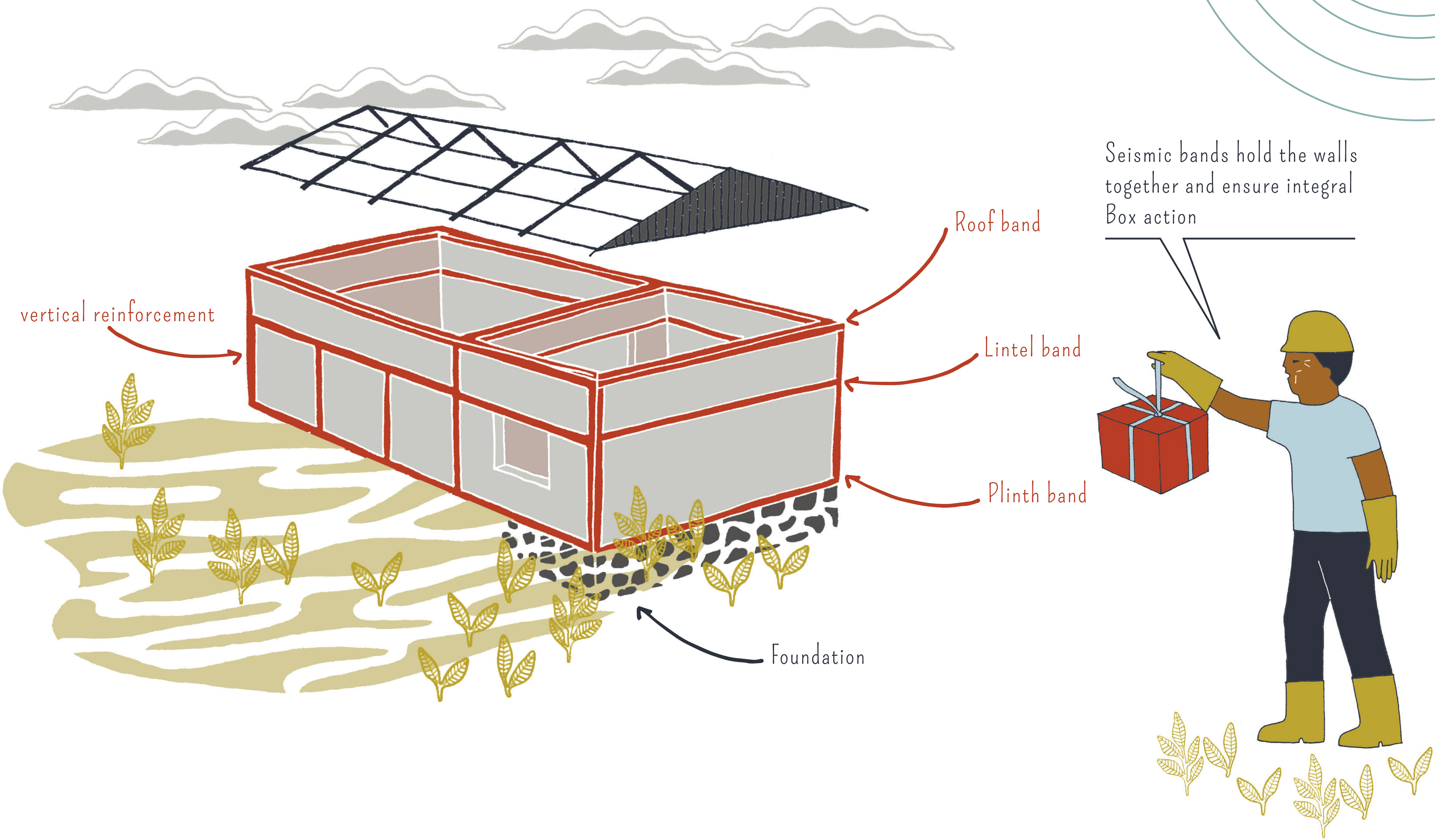
Vertical section of ditch
between two plateforms

4

(Re)build
earthquake-resistant traditional buildings



How to build earthquake-resistant traditional stone house (one storey) ?

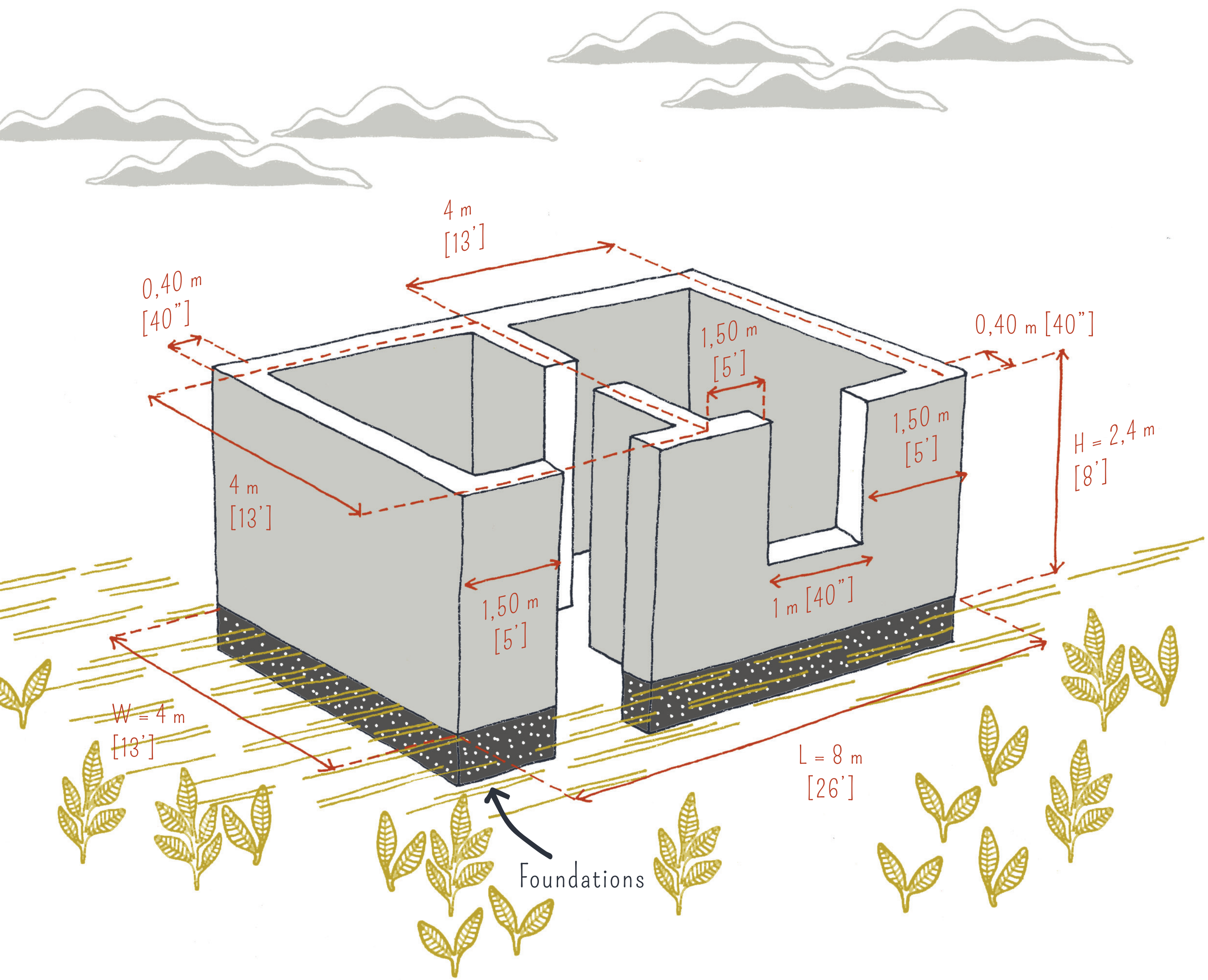


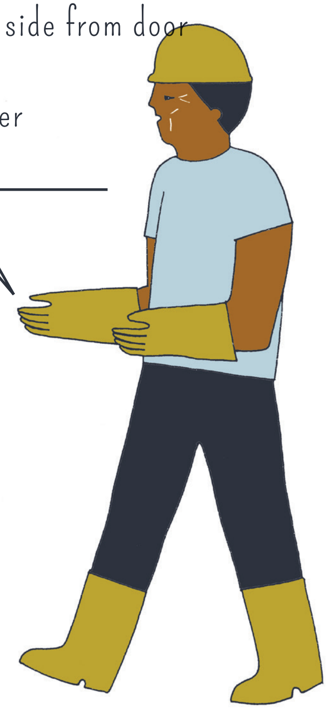
Seismic resistant layout

Fundamental ratios between wall thickness, maximum length, width and height of the walls must be respected.

a. Wall thickness (e) greater than 40 cm [40"].
b. Wall width (W) lower than half of wall length (L).
c. Maximum wall height lower than 6 times the wall thickness.
d. Maximum sub-length between cross-walls lower than 10 times the wall thickness and lower than 3 m [10'].
e. Wall length greater than 1.2 m [4'] must be preserved on each side from door and windows.
f. Window and door width lower than 1.2 m [4'].

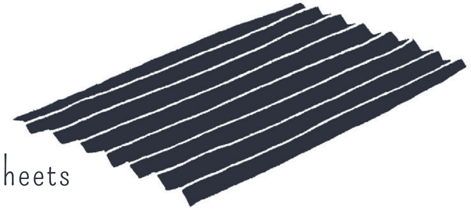
An example is given on the drawing

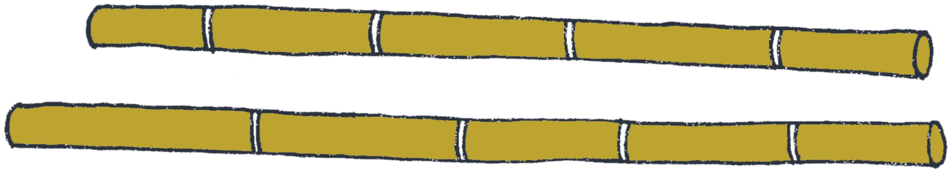




Building materials

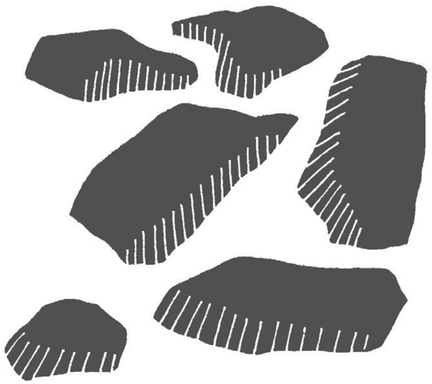
Mud mutar
As much as possible, it is better to use cement mortar (Cement 1; sand 3; water 1/3,) instead of mud mortar.





Roofing sheets

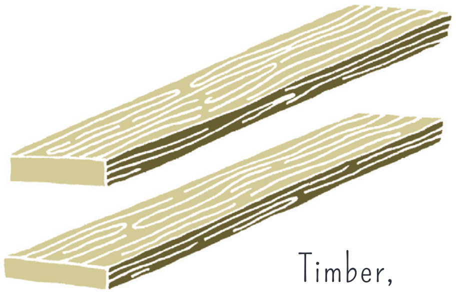
Bamboo
Matured bamboo ≥ 3 years old
to soak the bamboo in running water ≥ 3 weeks



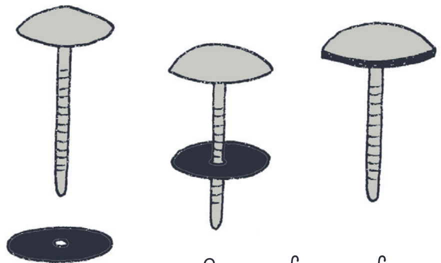
Rubble stones / Broken stones
Thickness ≥ 50 mm [2"]
With, lenghth ≥ 150 mm [6"]
size as uniform as possible

nails

anchor steel

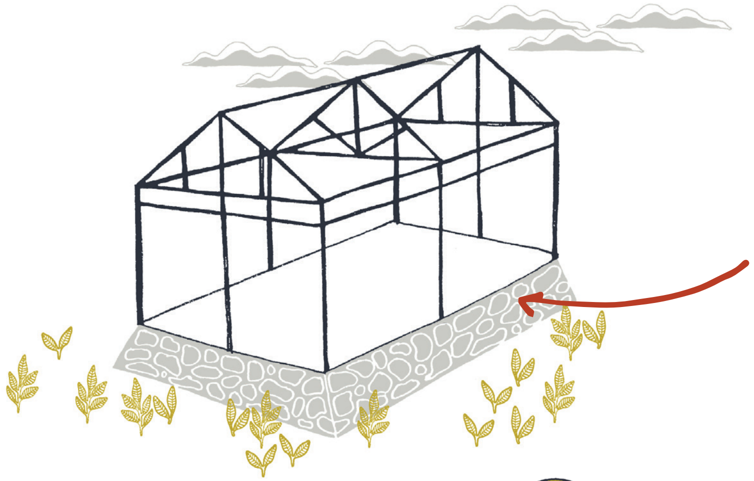


Timber,
Dry, straight,
no cracks and no notch



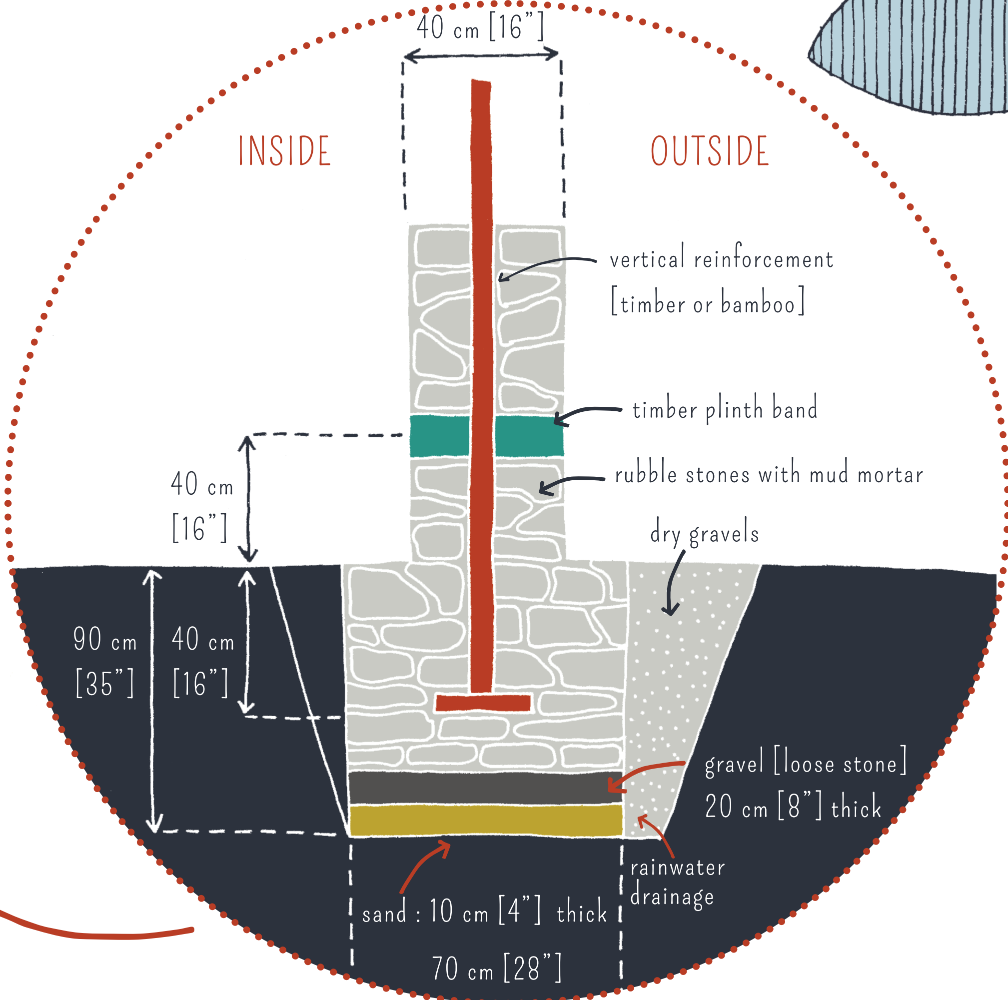
Screw for roof

Foundations

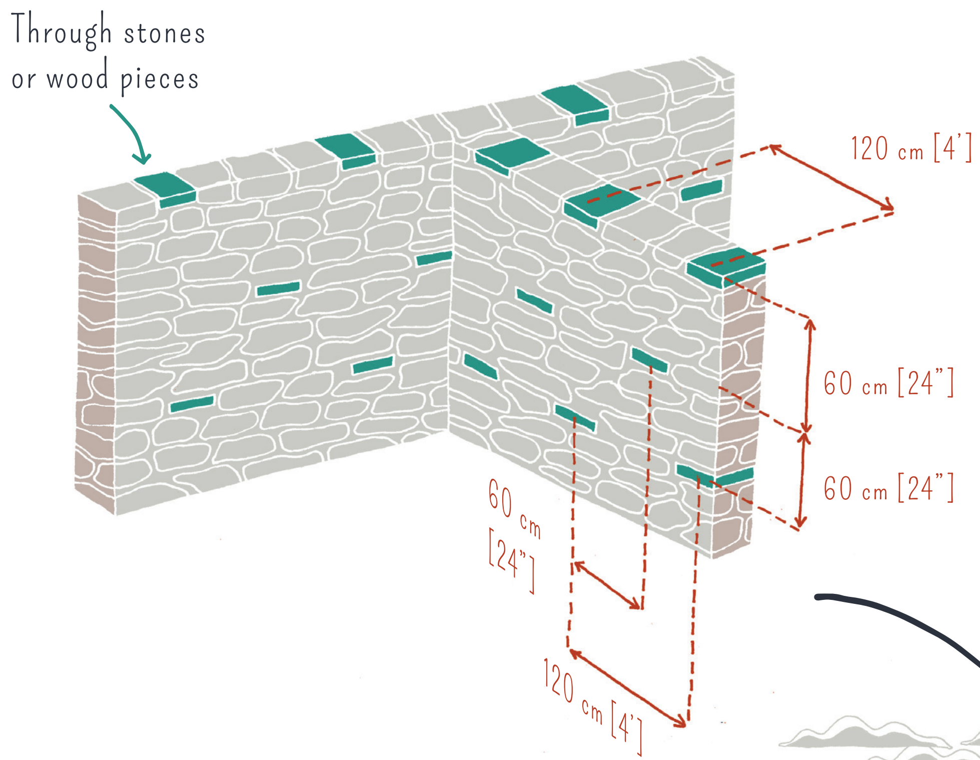


Protection of vertical wood reinforcement from moisture :
- applying a protective coating (bitume or melted paraffin wax)
- or layer of polyethylene around wood pillar.

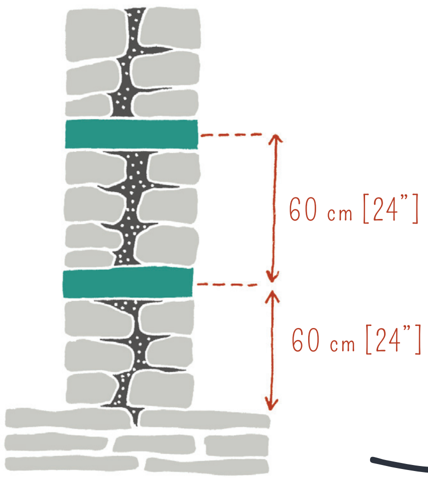
Dig a trench under the future walls to perform the building foundations and add an outside rainwater drainage network.

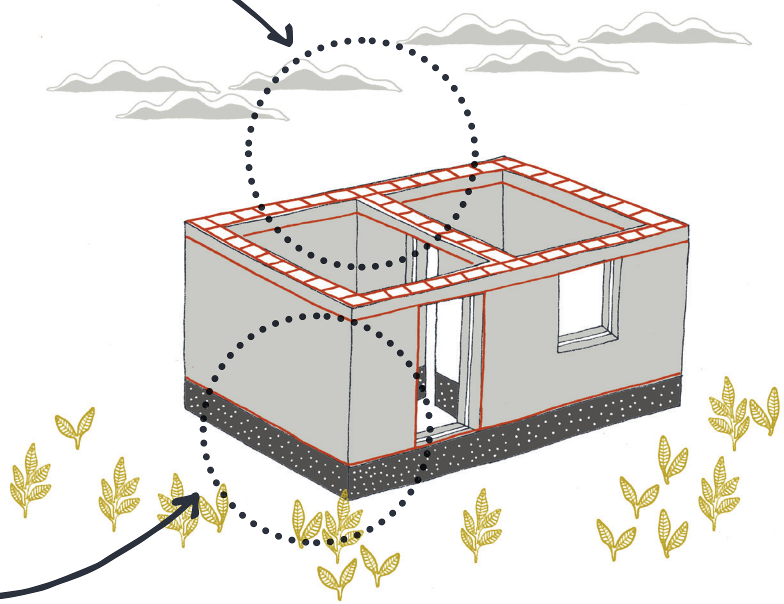


Walls in rubble stones with mud mortar

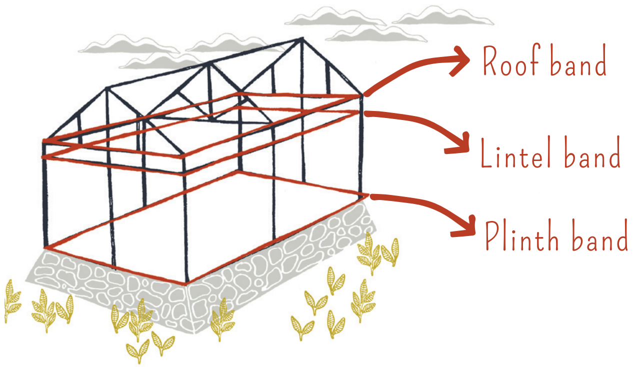


To avoid stone wall delamination, put regularly spaced through stones or wood pieces across the wall thickness.

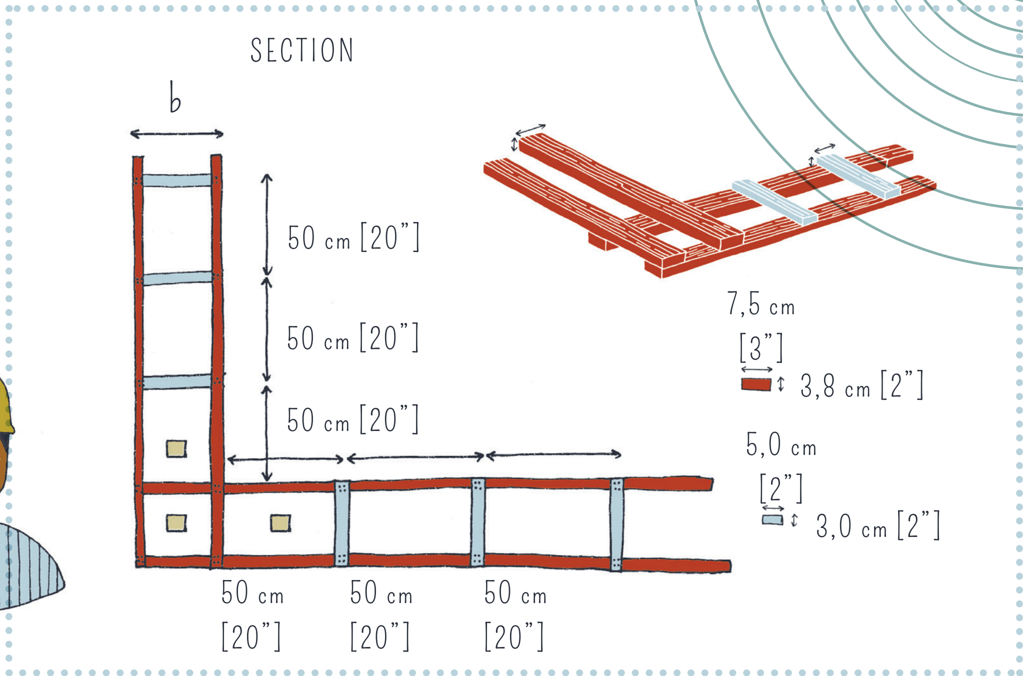


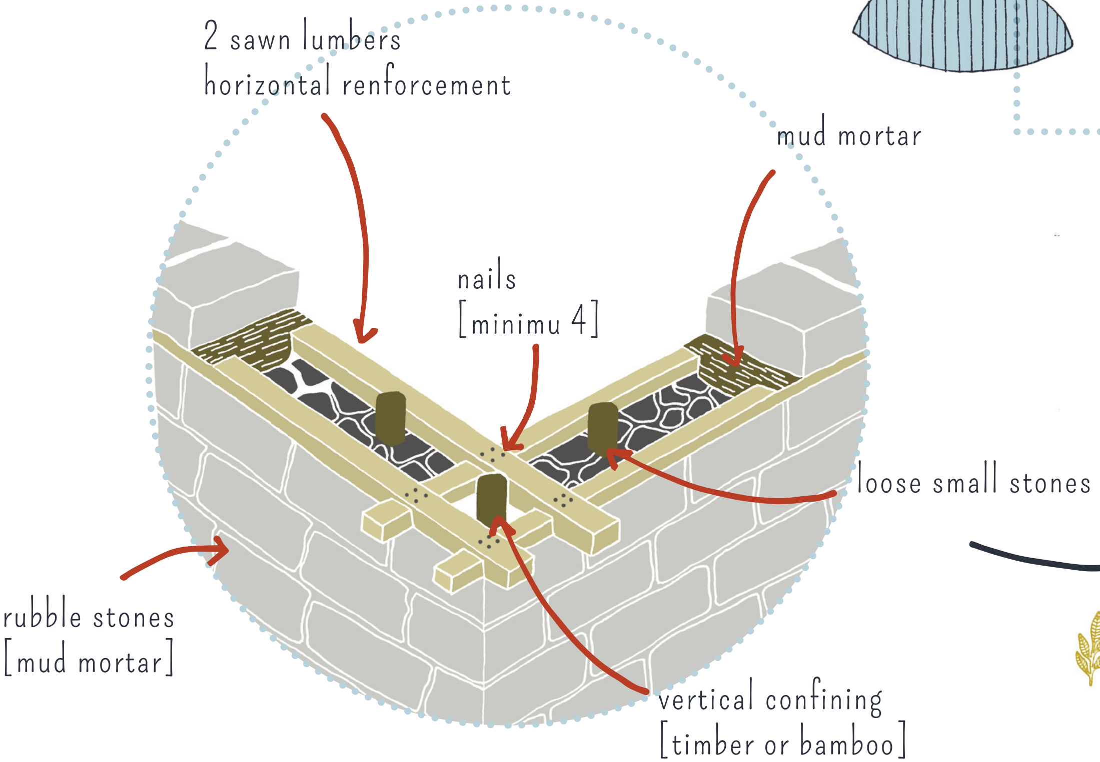


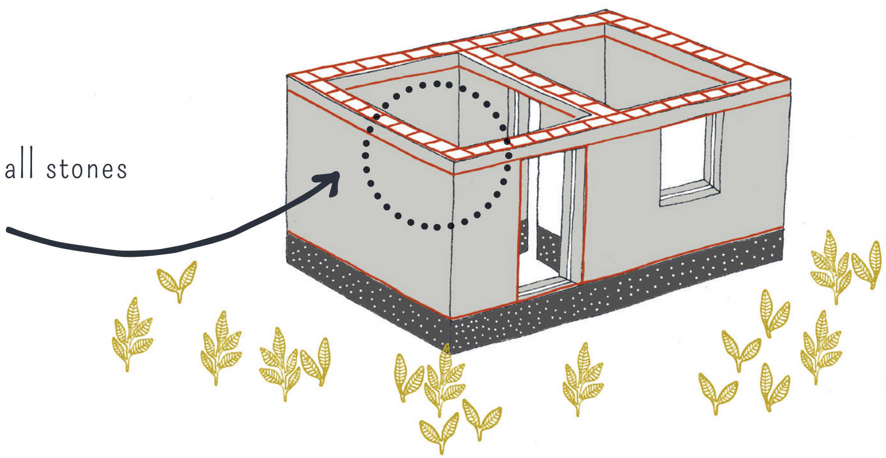
Detail of seismic bands with WOOD



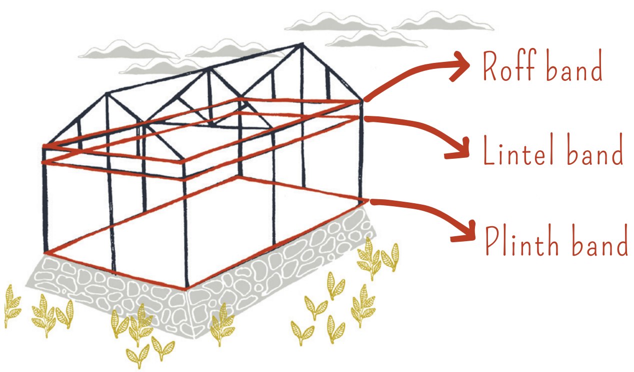
As previously mentioned, seismic bands hold the walls together and ensure integral Box action. If these seismic bands (plinth, lintel and roof) are made with WOOD, apply the present design.



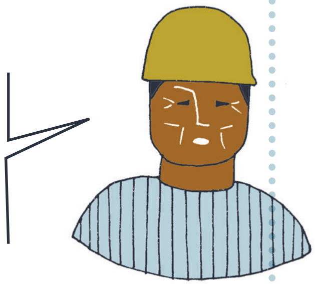


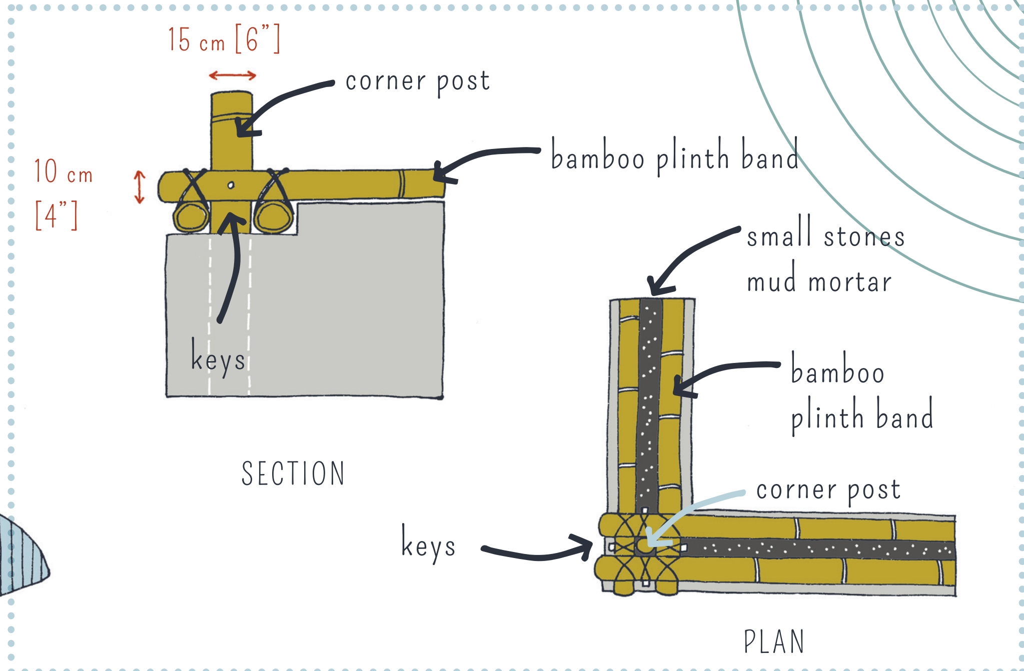


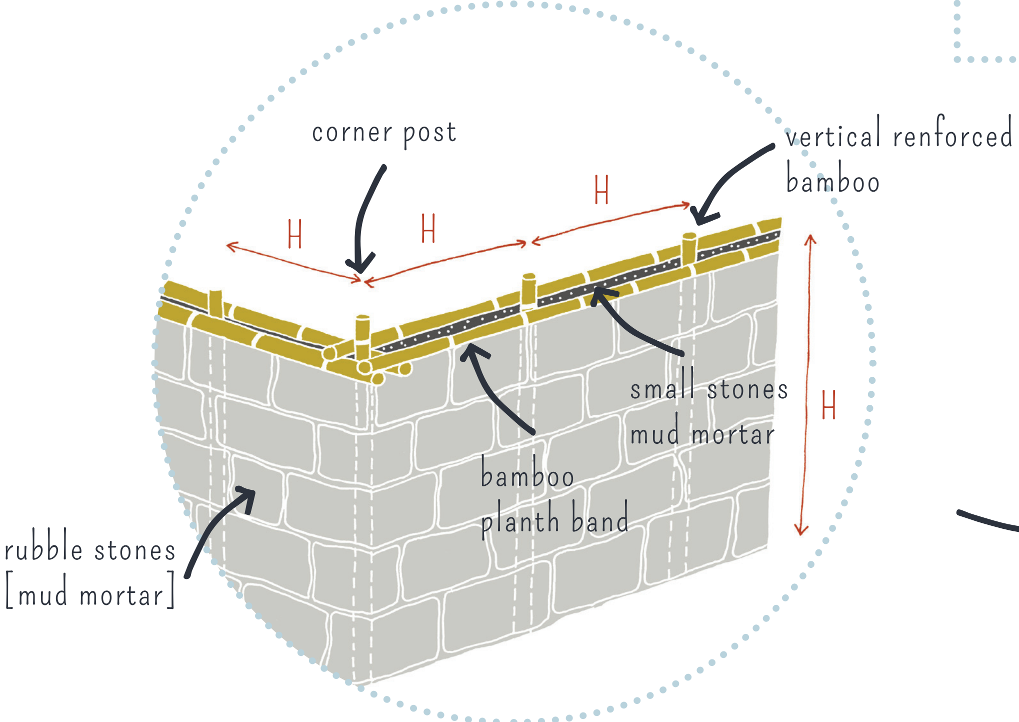
Detail of seismic bands with BAMBOO

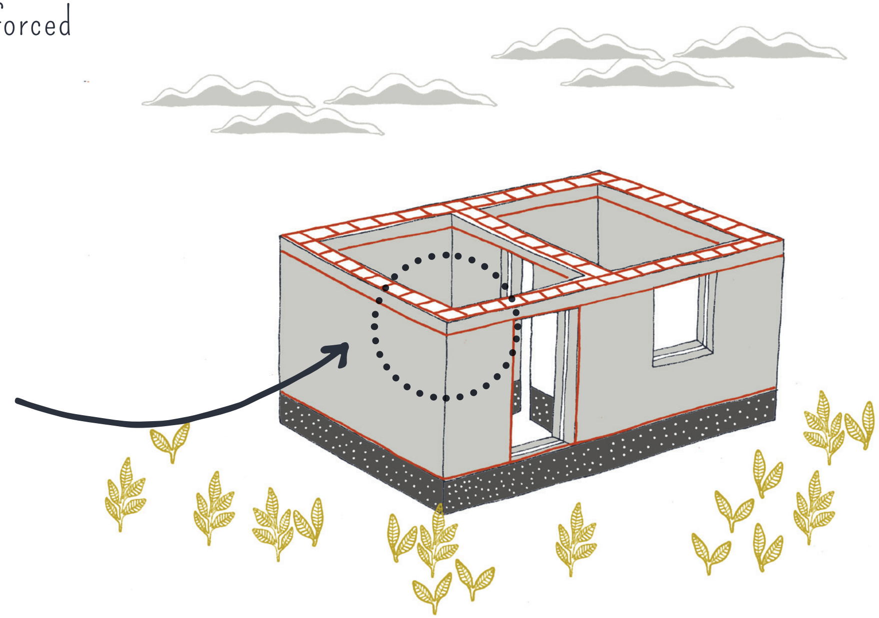


If these seismic bands (plinth, lintel and roof) are made with BAMBOO, apply the present design. Note spacing of vertical bamboo reinforcement.

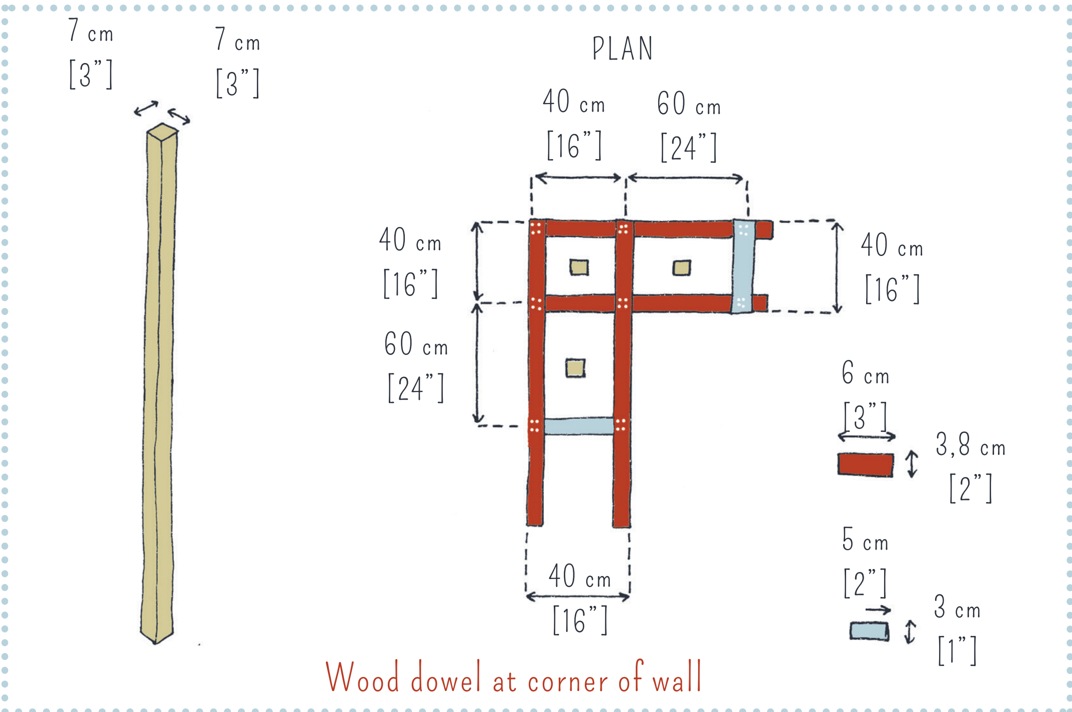








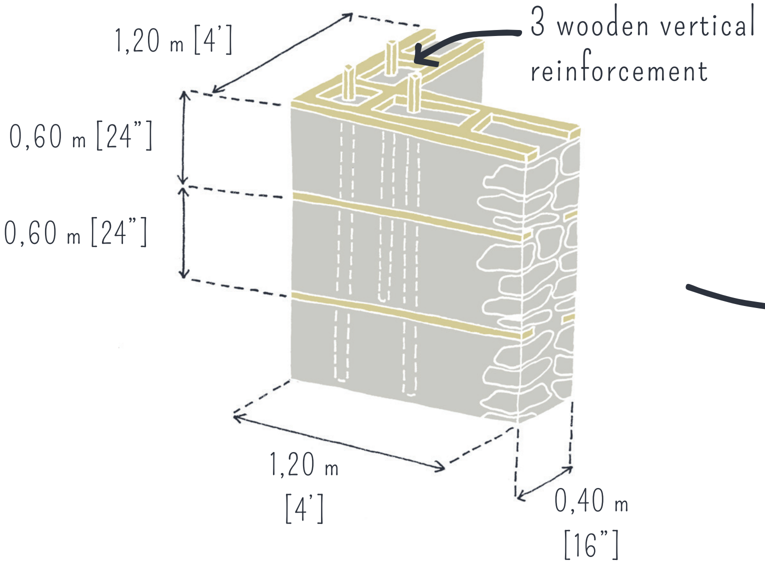
Connection between transverse walls

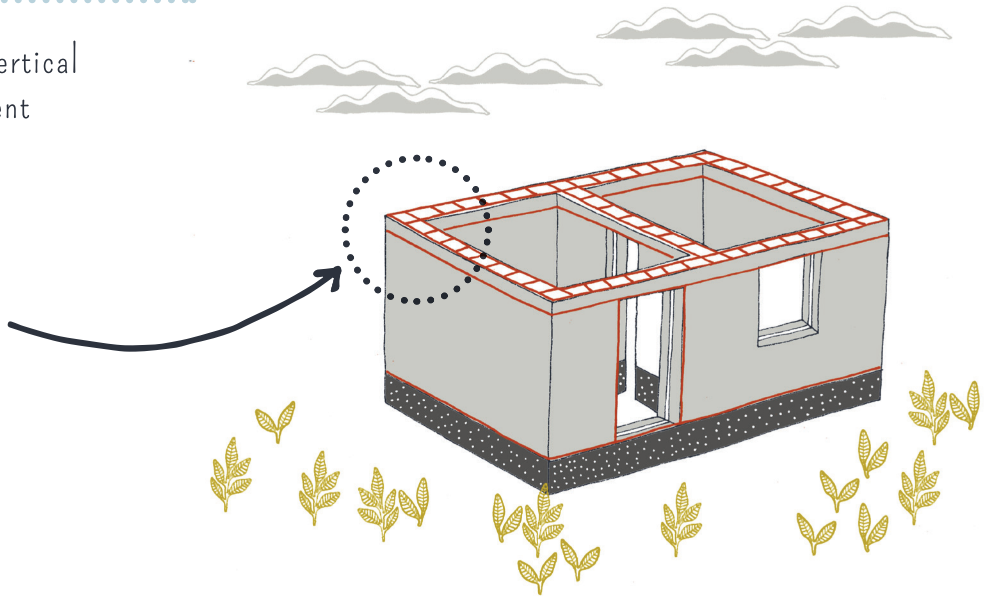


Wood dowel at corner of wall

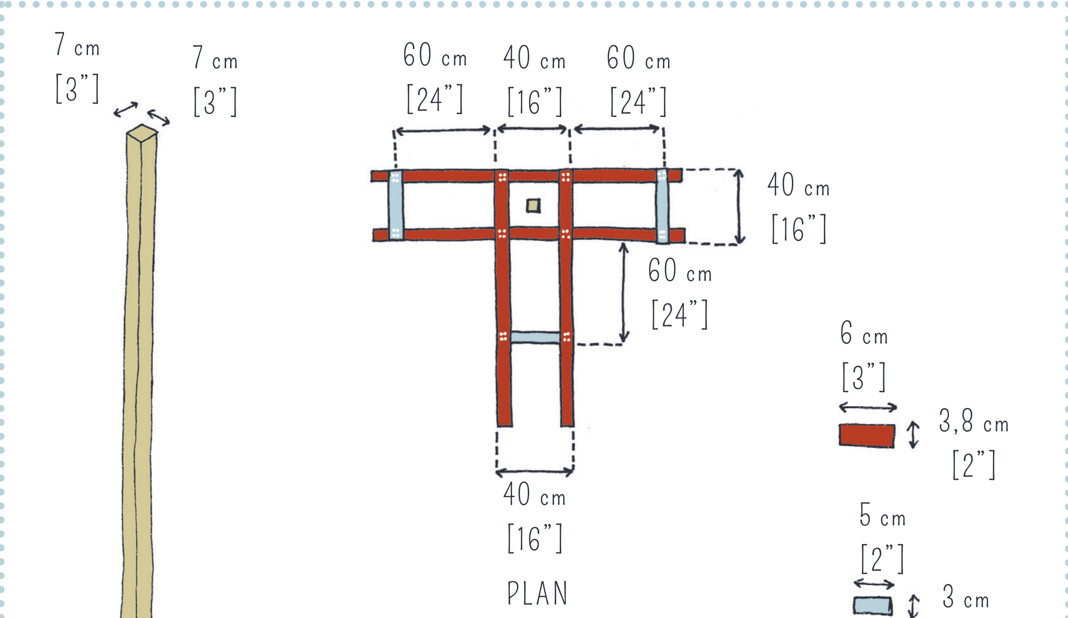
To further strengthen transverse walls (corner) horizontal timber stiches may be used. Minimum length in each wall is 1.20 m [4']. They are placed in every 60 cm [24"] in height.

Reinforce wall corners with 3 vertical timber or bamboo wood dowel greater than 7 cm [3"] in diameter.





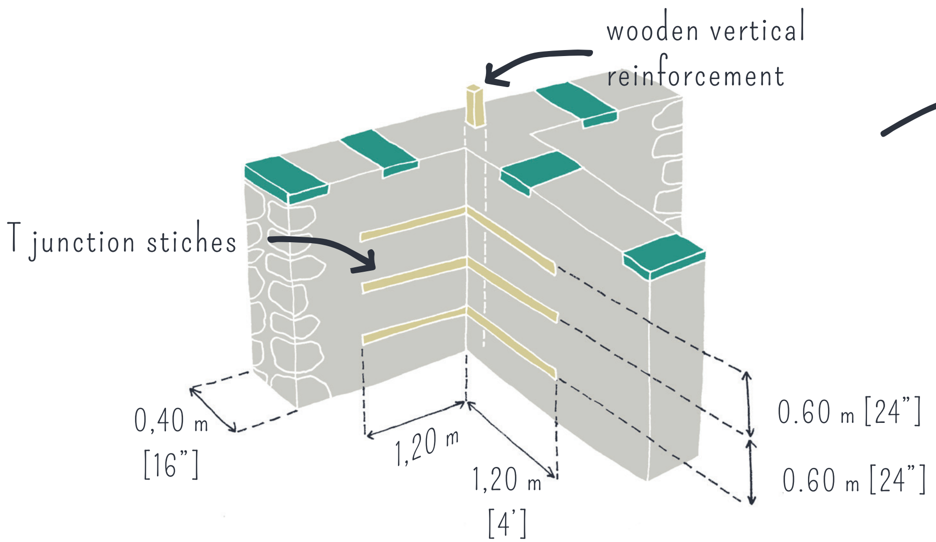
Connection between transverse walls

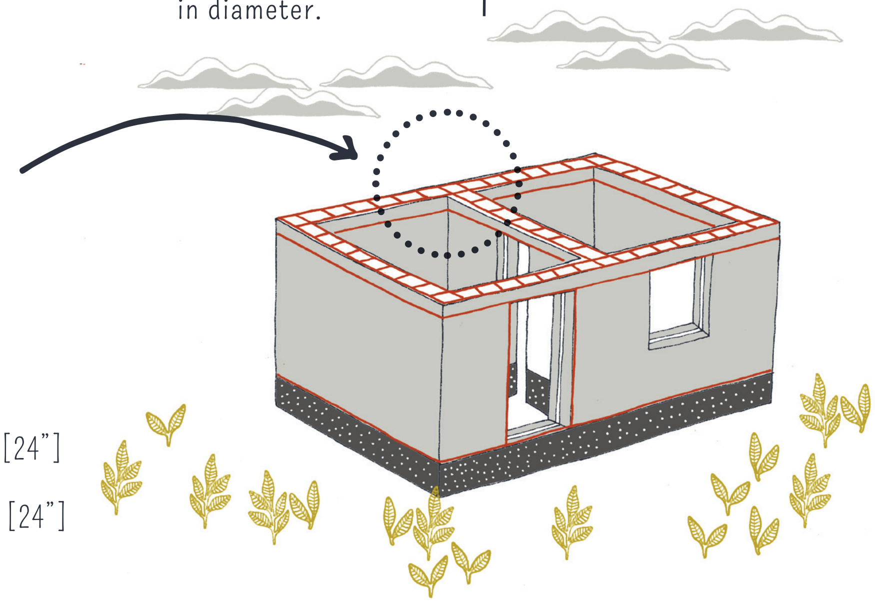


Wood dowel at T junction wall

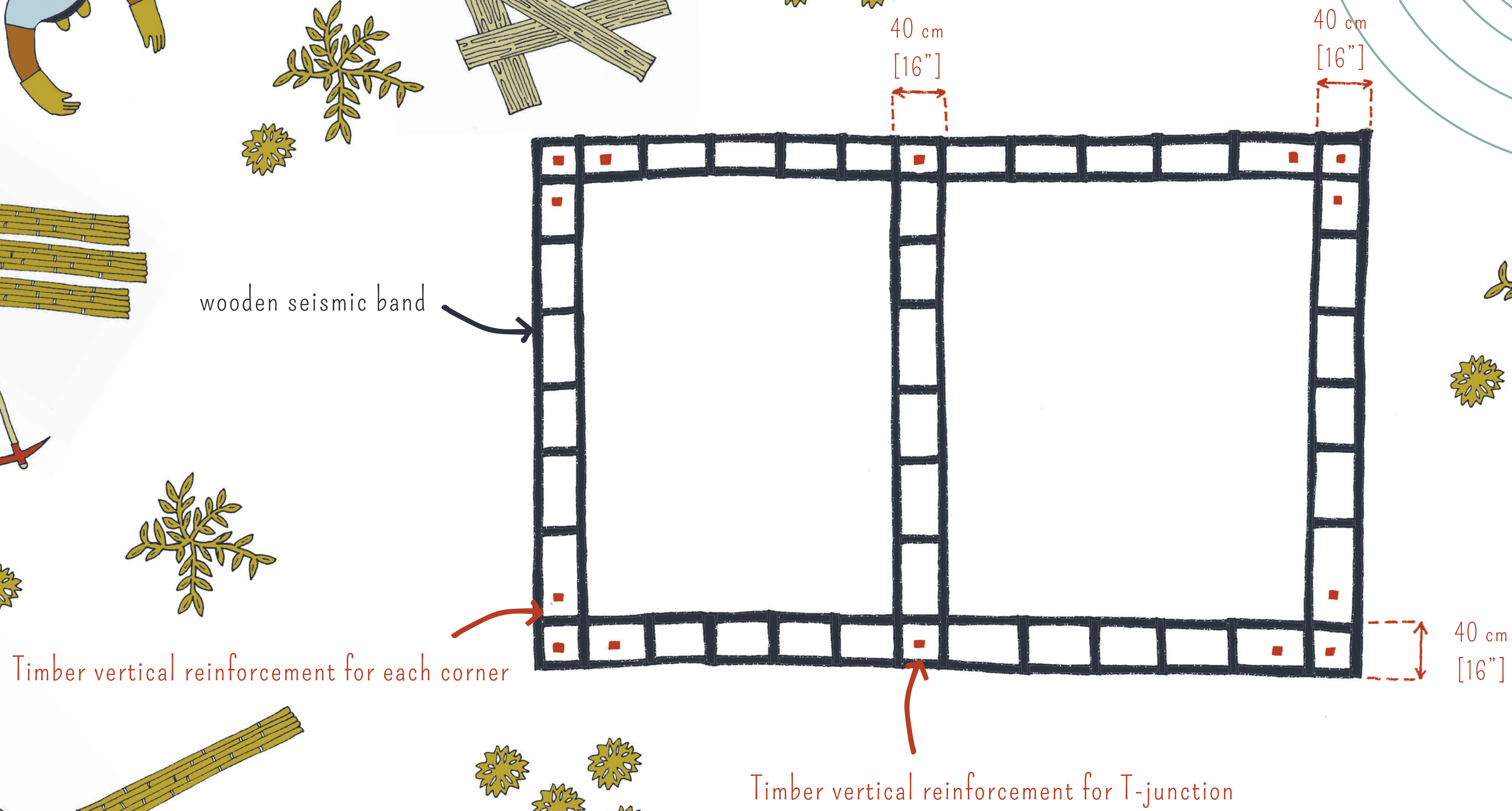
To further strengthen transverse walls (corner) horizontal timber stiches may be used. Minimum length in each wall is 1.20 m [4']. They are placed in every 60 cm [24"] in height.

Reinforce wall corners with 3 vertical timber or bamboo wood dowel greater than 7 cm [3"] in diameter.



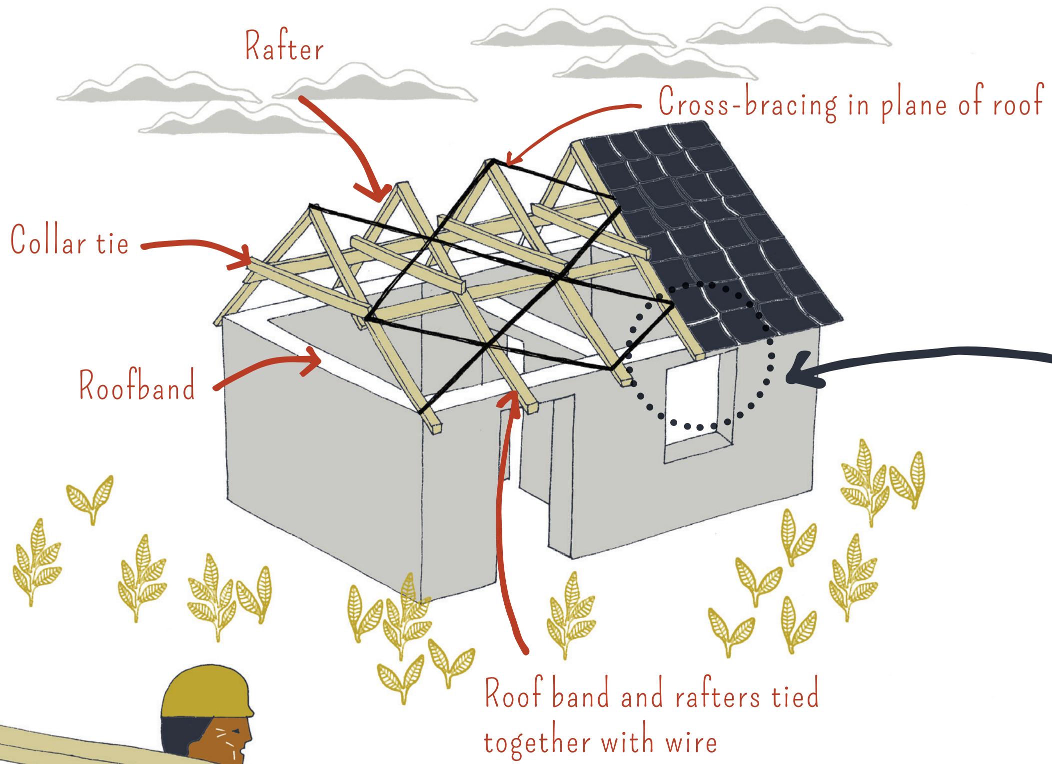


Timber vertical reinforcement



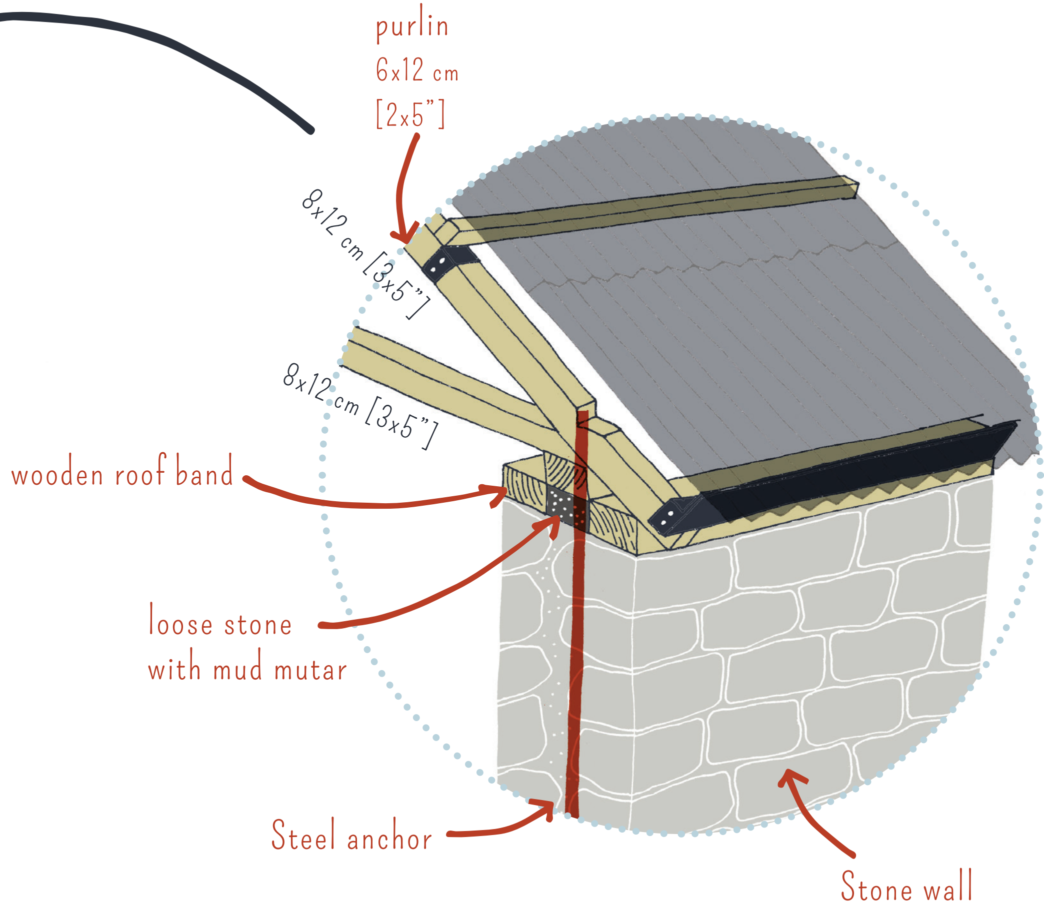
Put vertical reinforcement at each junction between walls (corner and T-junction) on the height from foundation to roof.

Timber roof

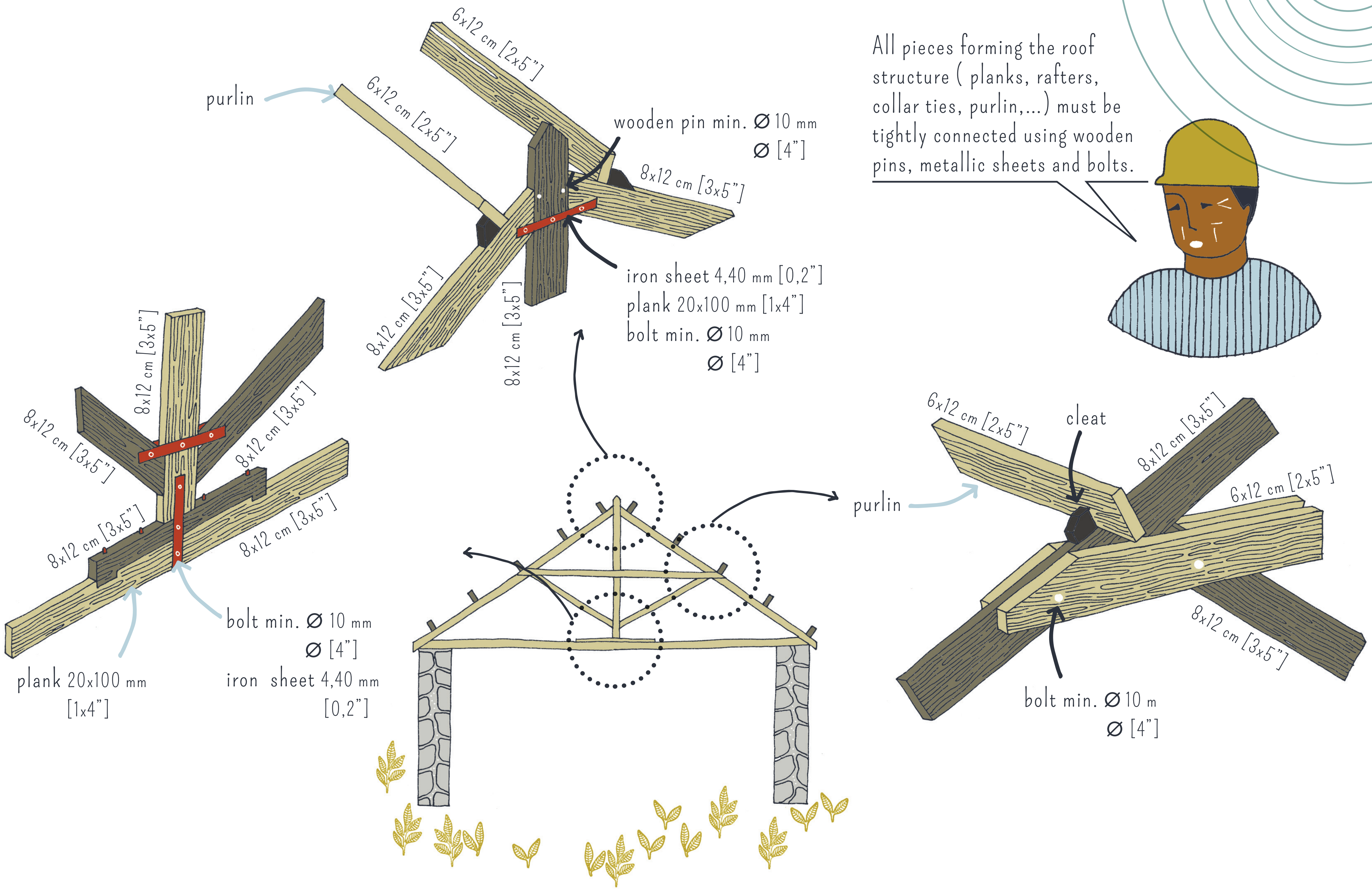


Roofs have two main parts: structure and cover.
Roofing structure must be light, well connected and adequately tied to the walls. Do not charge an attic with heavy load.

Steel anchor must be placed during the construction of stone wall. It is threated for fixing the roof with a bolt.



Timber roof



All pieces forming the roof structure (planks, rafters, collar ties, purlin,...) must be tightly connected using wooden pins, metallic sheets and bolts.
6x12 cm [2x5"]
purlin
6x12 cm [2x5"]
wooden pin min. Ø 10 mm
Ø [4"]
8x12 cm [3x5"]
iron sheet 4,40 mm [0,2"]
plank 20x100 mm [1x4"]
bolt min. Ø 10 mm
Ø [4"]
8x12 cm [3x5"]
8x12 cm [3x5"]
8x12 cm [3x5"]
8x12 cm [3x5"]
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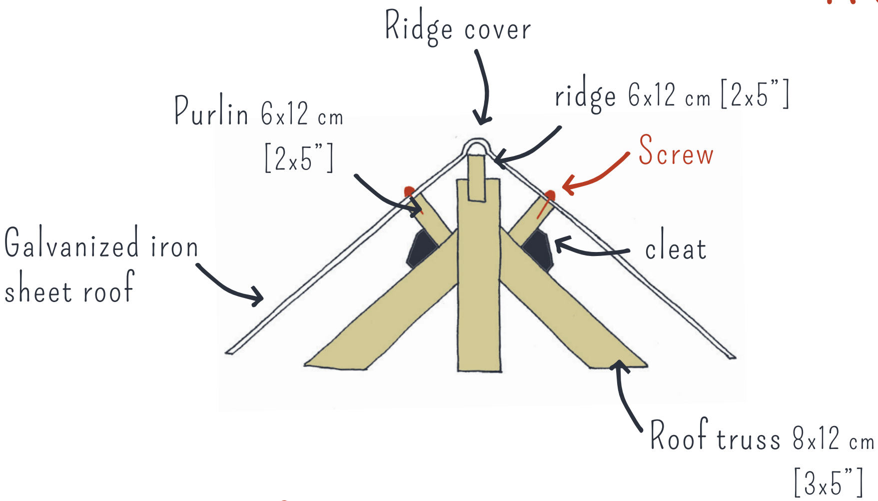
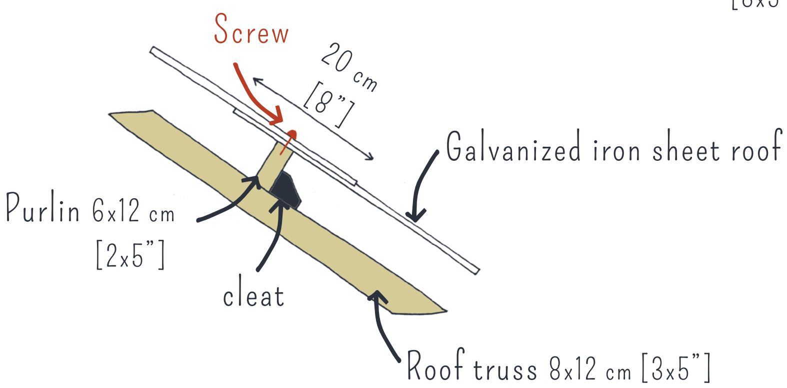
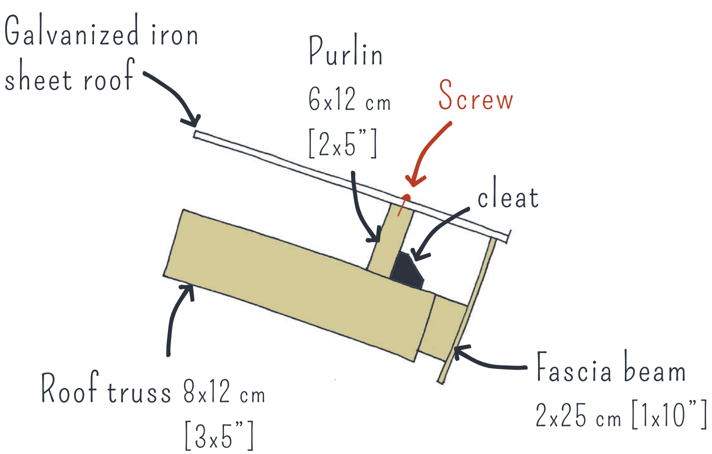
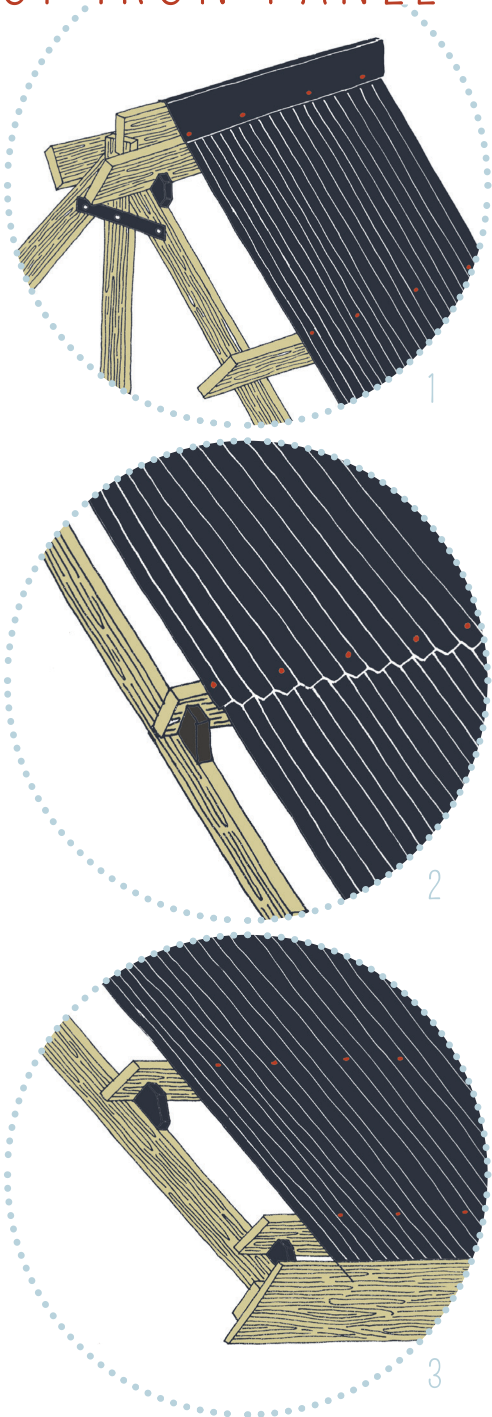
8x12 cm [3x5"]
8x12 cm [3x5"]
plank 20x100 mm
[1x4"]
bolt min. Ø 10 mm
Ø [4"]
iron sheet 4,40 mm
[0,2"]
6x12 cm [2x5"]
cleat
8x12 cm [3x5"]
purlin
6x12 cm [2x5"]
8x12 cm [3x5"]
bolt min. Ø 10 m
Ø [4"]

Roof iron panel

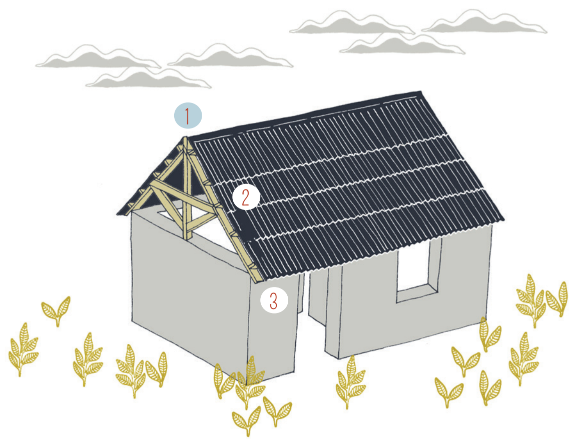






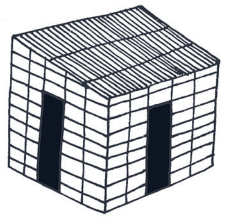


Galvanized metallic panels are fixed on the wooden roof structure using screws. Overlapping of galvanized metallic panels must be of 30 cm [12"] on large side and 10 cm [4"] along short side. Use a minimum of 8 screws by panel.

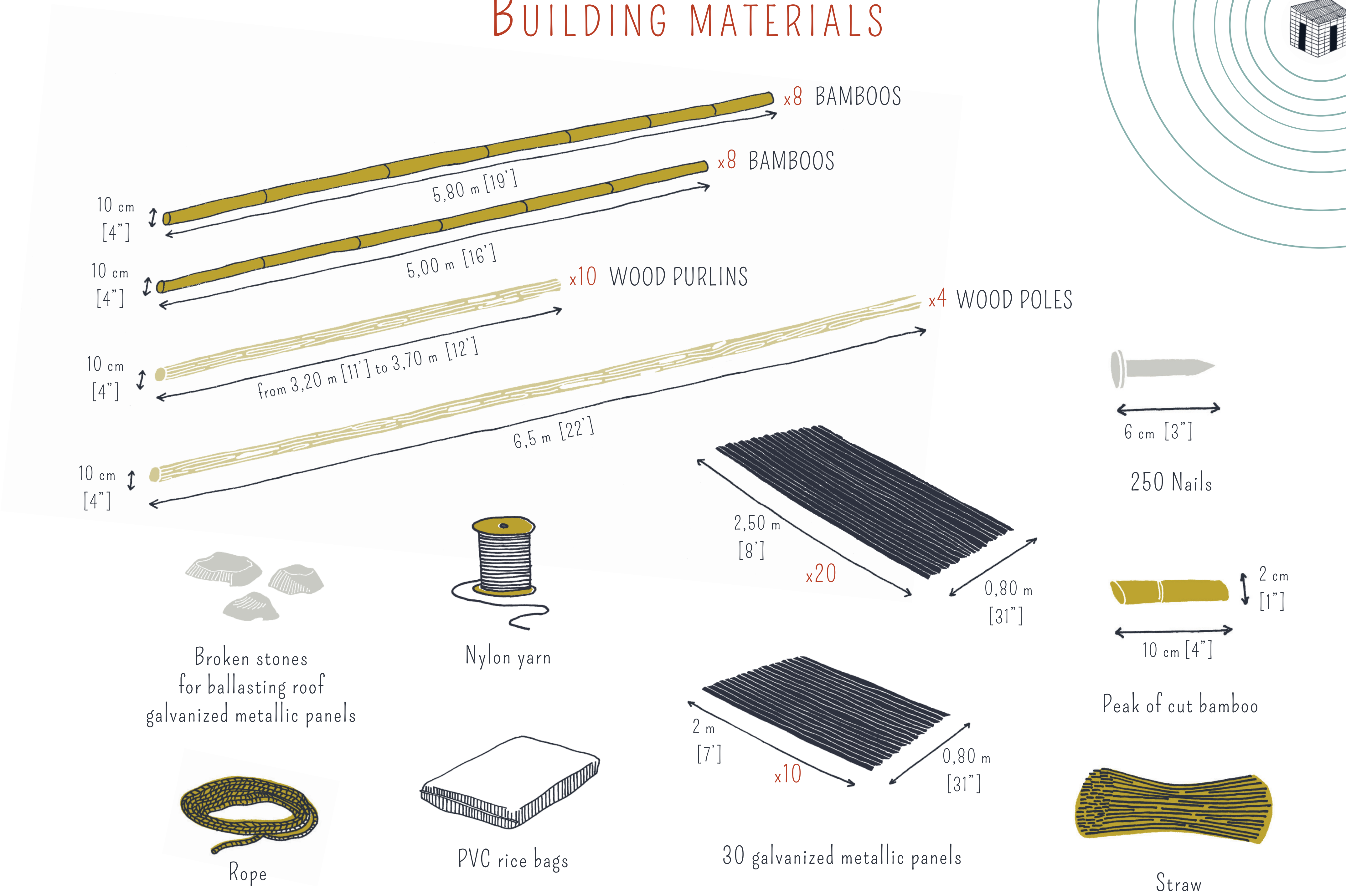


5

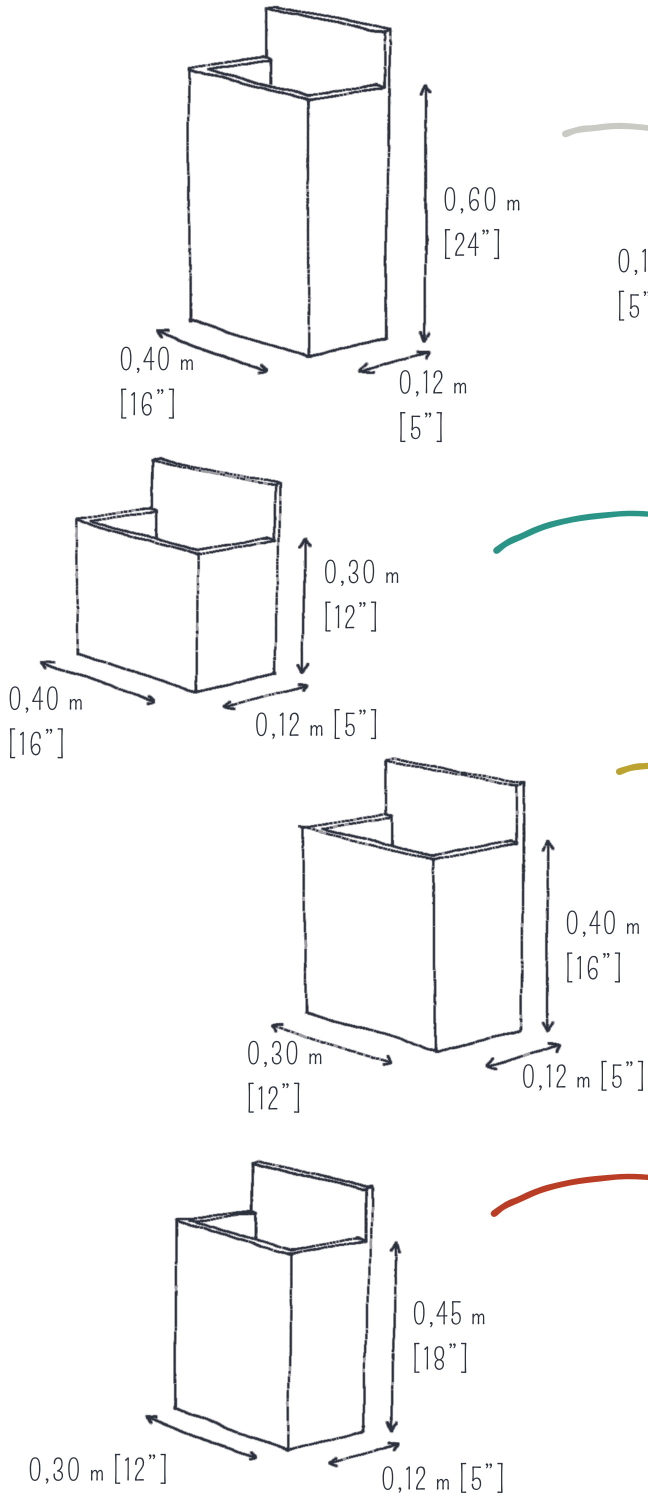
Build earthquake-resistant bag-buildings

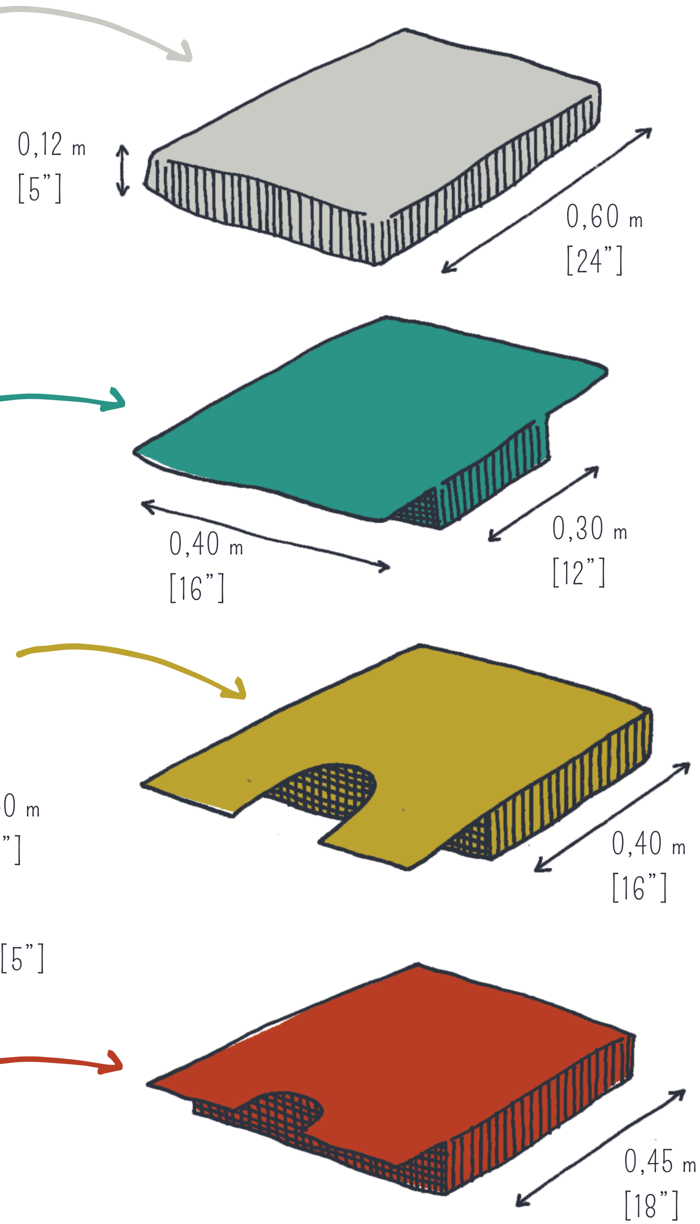


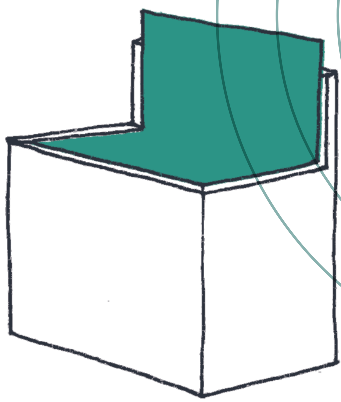
Building materials



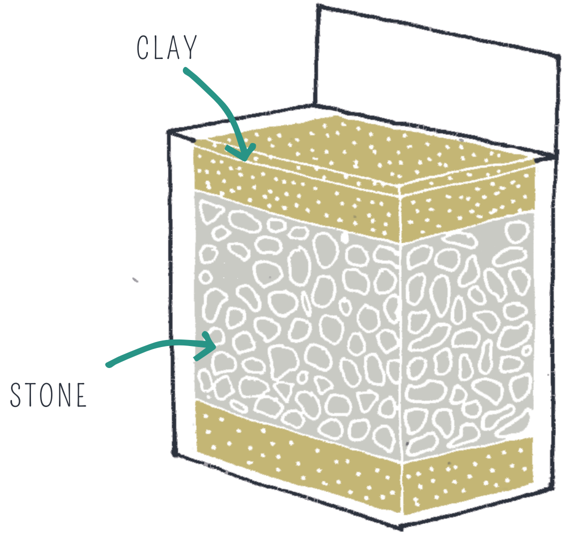
Preparation of bags







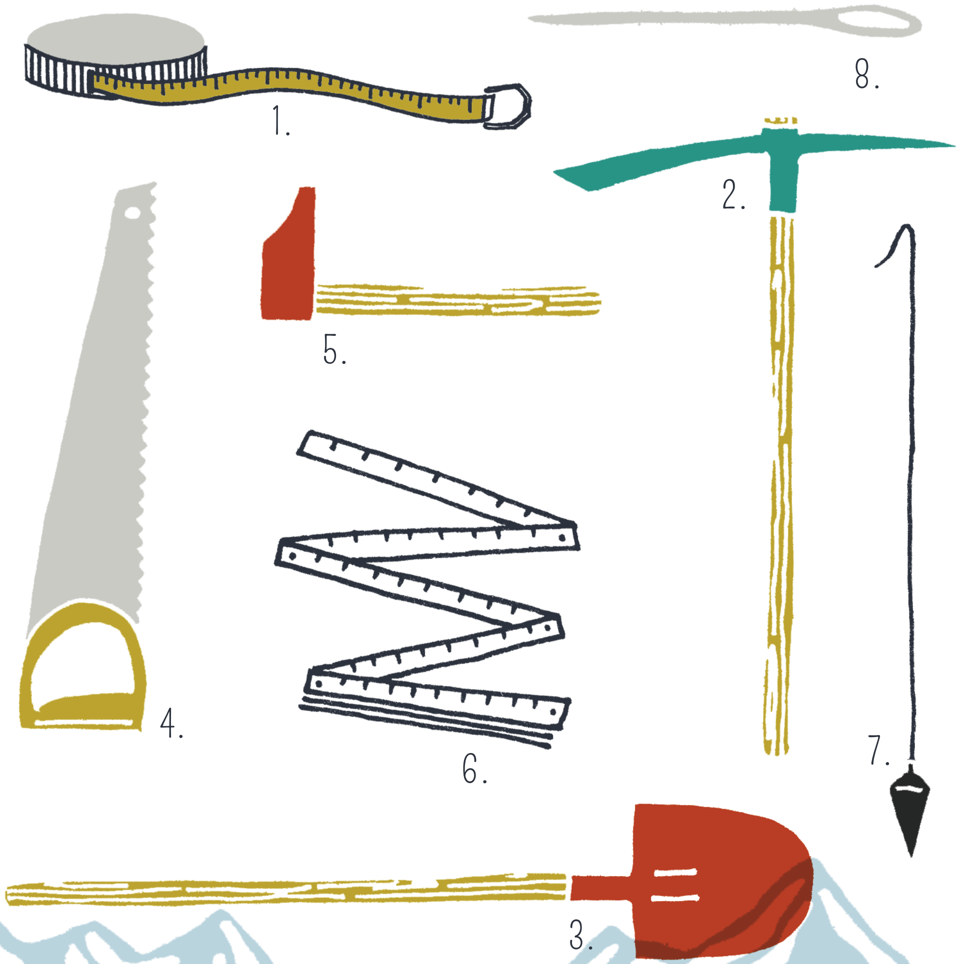
Example of a 30 cm [12"] bag filled at the good level within the template.



Bags must be filled as above shown : stone in the center part to increase the friction between bags ; and clay at the bottom and the top respectively to facilitate the insertion of the peaks of bamboo.

Construct 4 wooden templates to fill bags at adequate level.

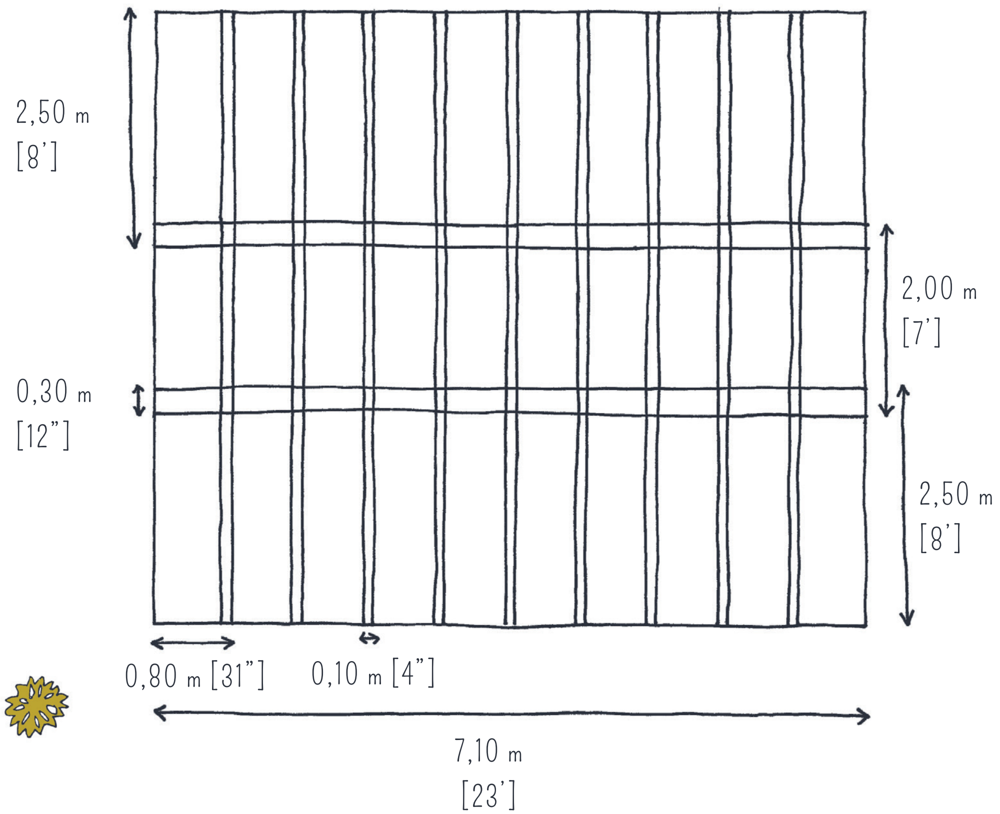
Minimum tools required



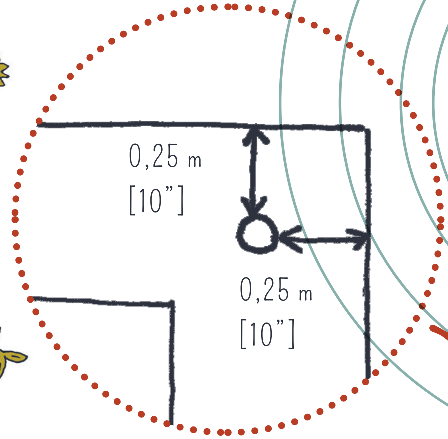
For the platforms preparation and excavations : 1, 2, 3
For the construction : 4, 5, 6, 7, 8

FOUNDATIONS

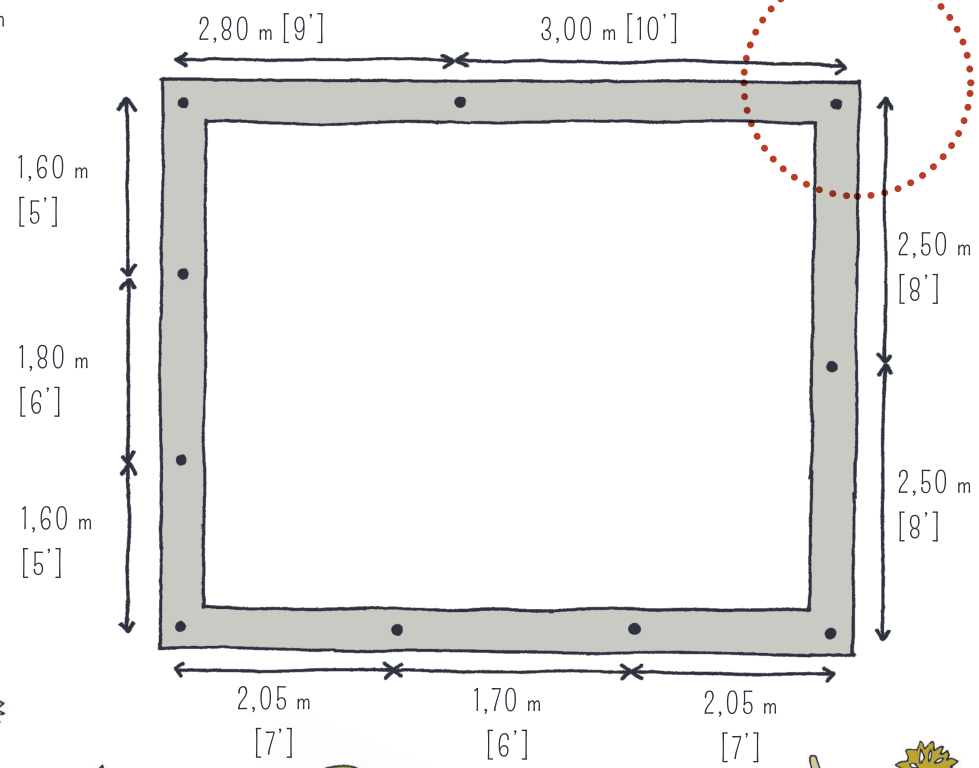
MAP VIEW OF THE DIMENSIONS OF THE PROJECTED BUILDING



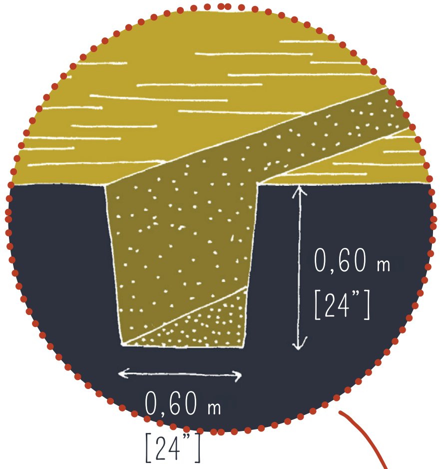
The dimension of the projected building is directly derived from the number and sizes of galvanized metallic panels, by considering an overlap of 10 cm [4"] and 30 cm [12"] for the short and large sides respectively. Here, it has been considered 10 and 20 units of 80x200 cm [31"x7'] and 80x250 cm [31"x8'] galvanized metallic panels respectively.



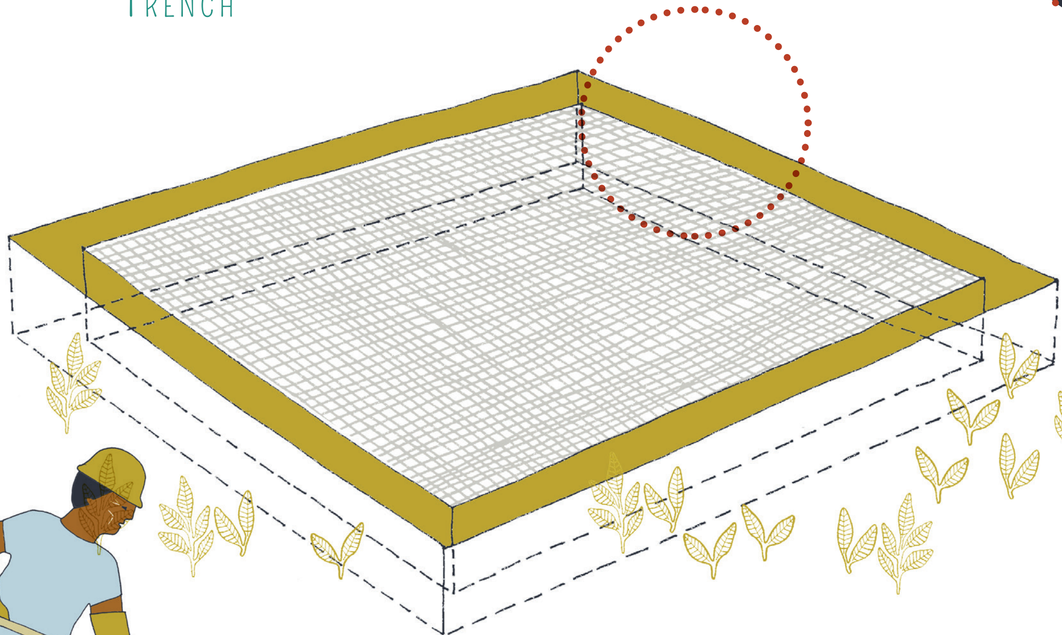
MAP VIEW OF POLE LOCATION AND THE TRENCH TO BE EXCAVATED FOR THE BUILDING FOUNDATIONS



Foundations

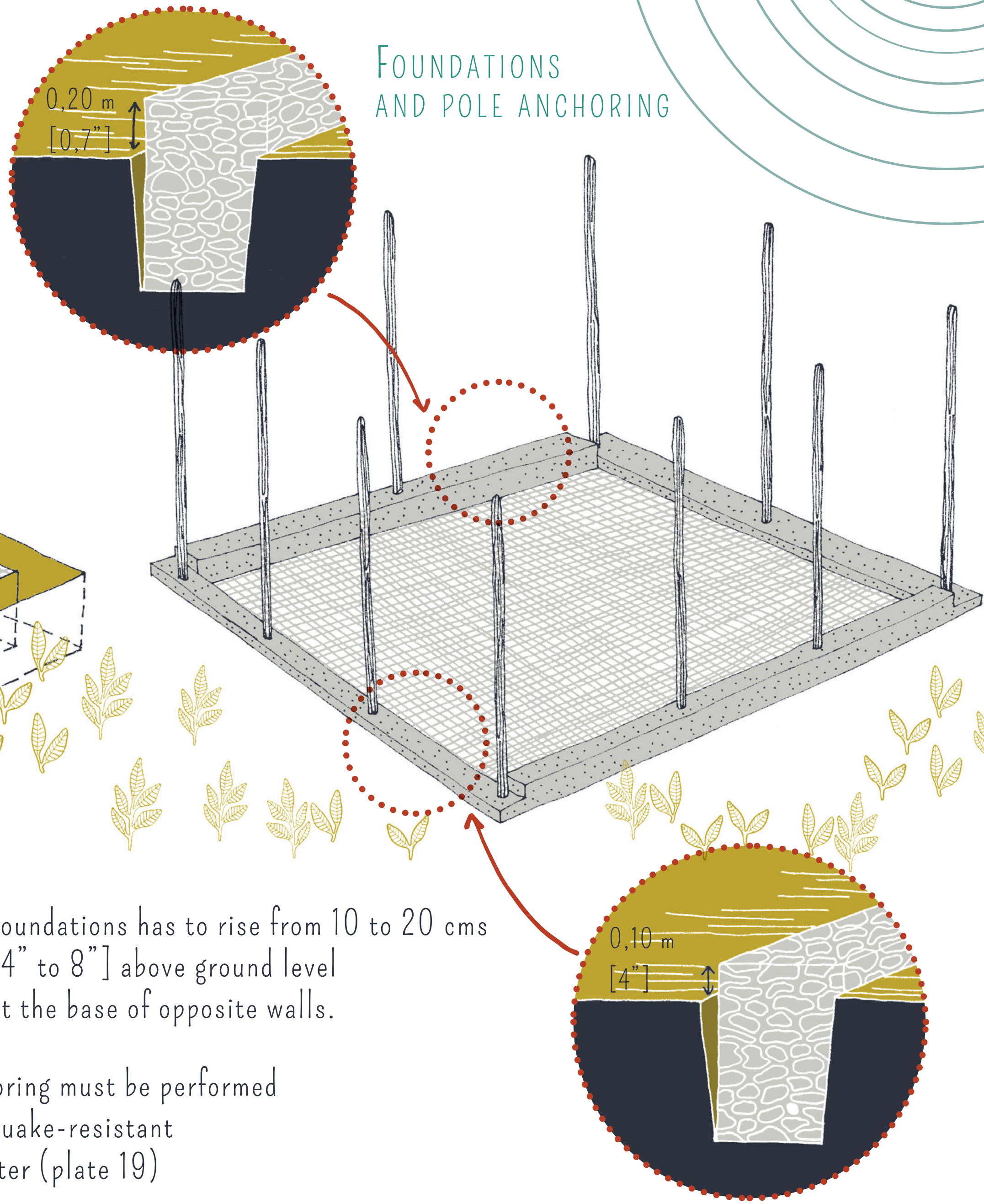


Trench



Dig a trench under the future walls to perform the building foundations.

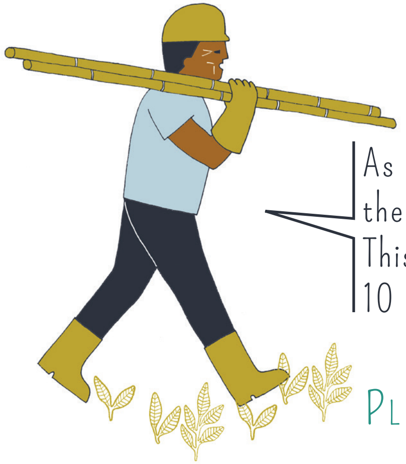
Foundations and pole anchoring



Foundations has to rise from 10 to 20 cms [4" to 8"] above ground level at the base of opposite walls.

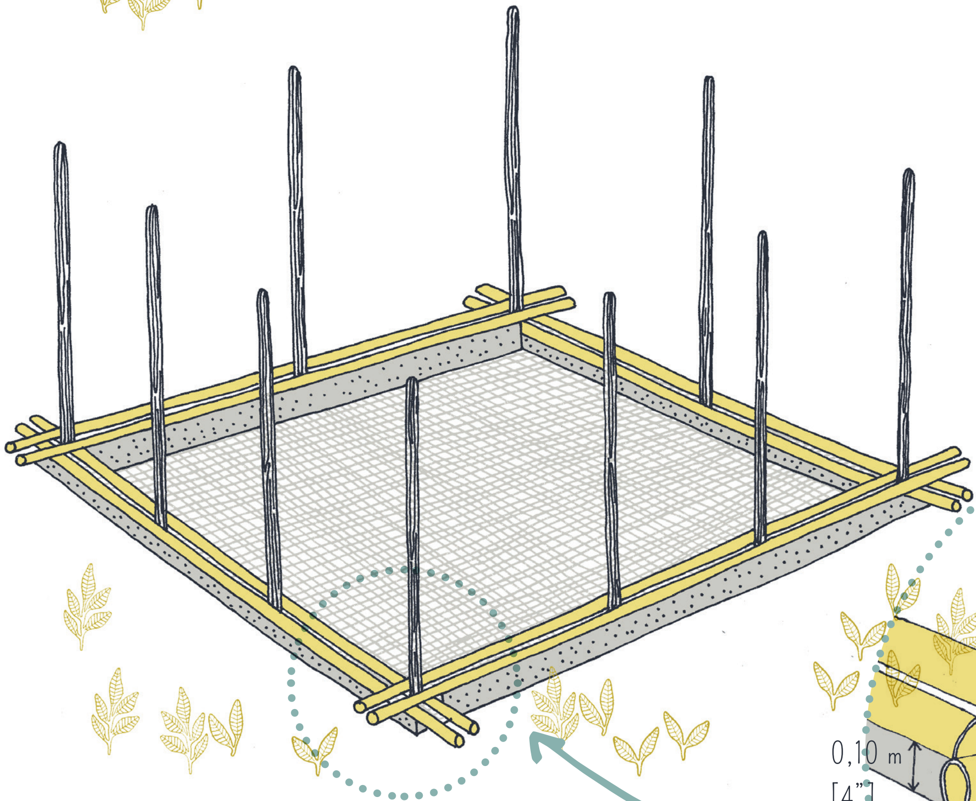
Foundations and pole anchoring must be performed as in the "(Re)build earthquake-resistant traditional buildings" chapter (plate 19)

Plinth seismic band implementation and connections with foundations



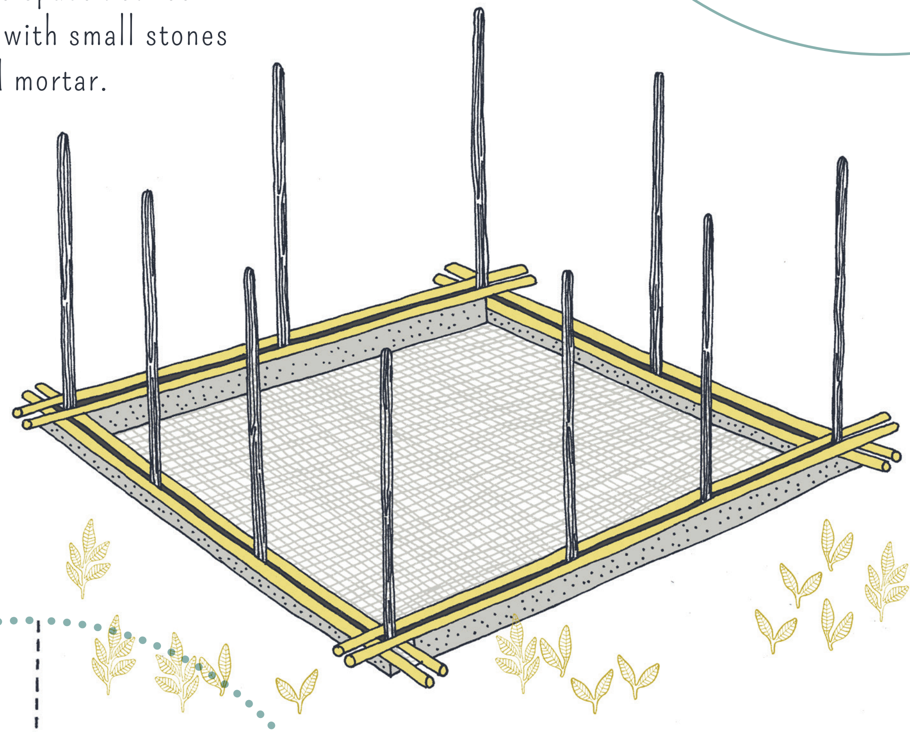
As previously mentioned, seismic bands hold the walls together and ensure integral Box action. This plinth seismic band is made of double bamboo, 10 cm [4"] in diameter, at the base of each wall.

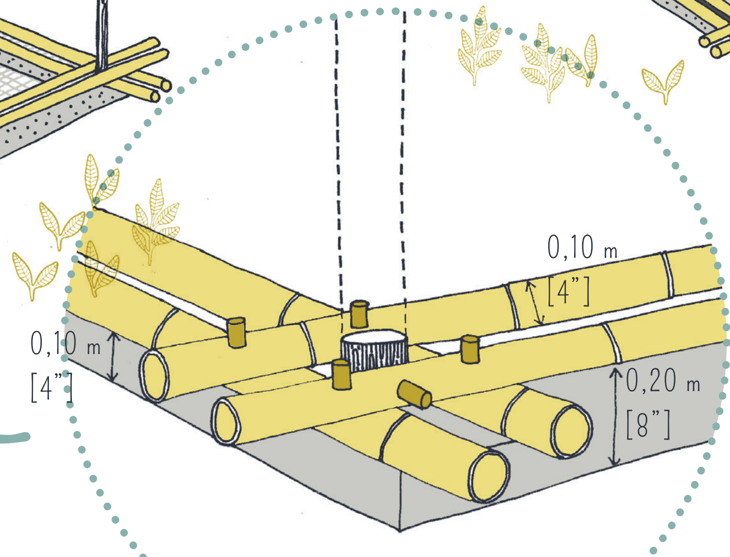
Plinth seismic band at the base of each wall



Infilling of the plinth seismic band

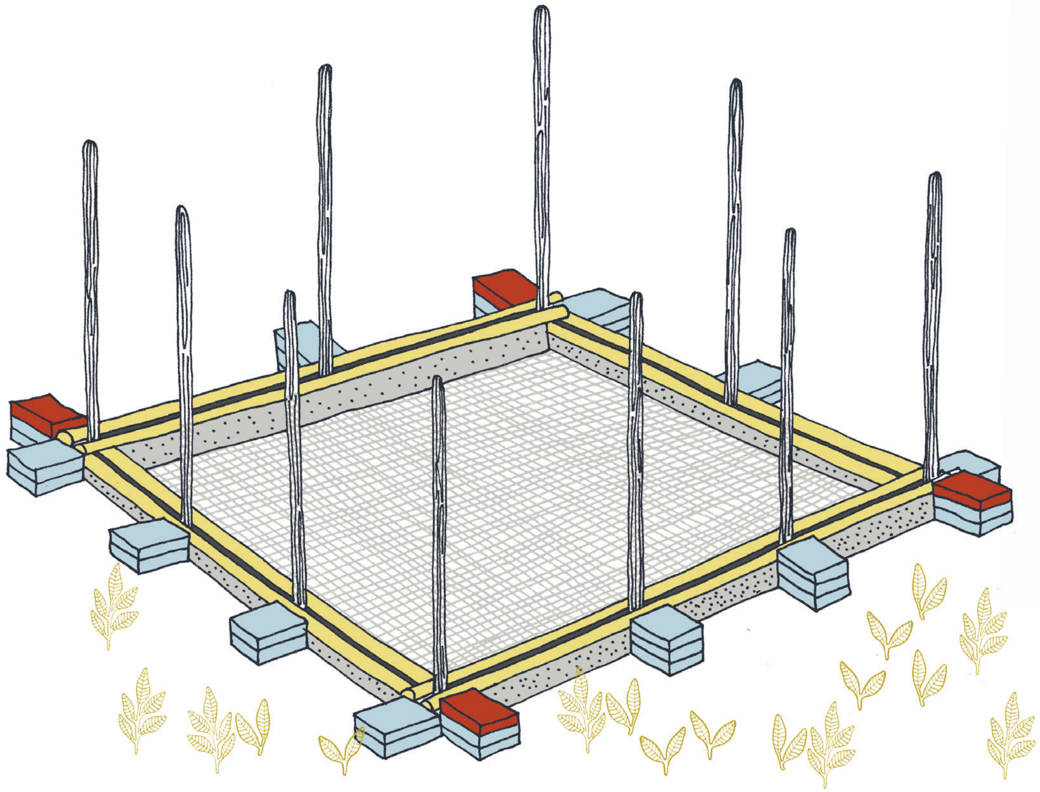
Infill the space between bamboo with small stones and mud mortar.





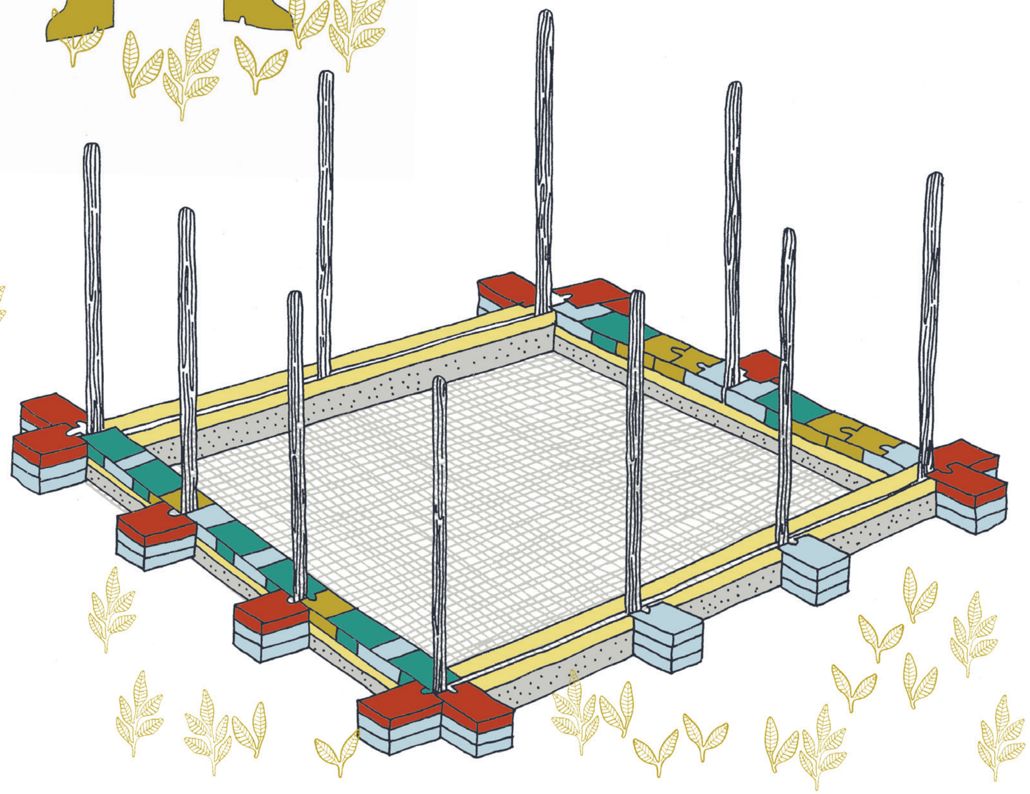
At each wall corner, bamboo are closely connected (i) some with the others and (ii) with vertical poles by means of cleats.

Construction above foundations and plinth seismic band



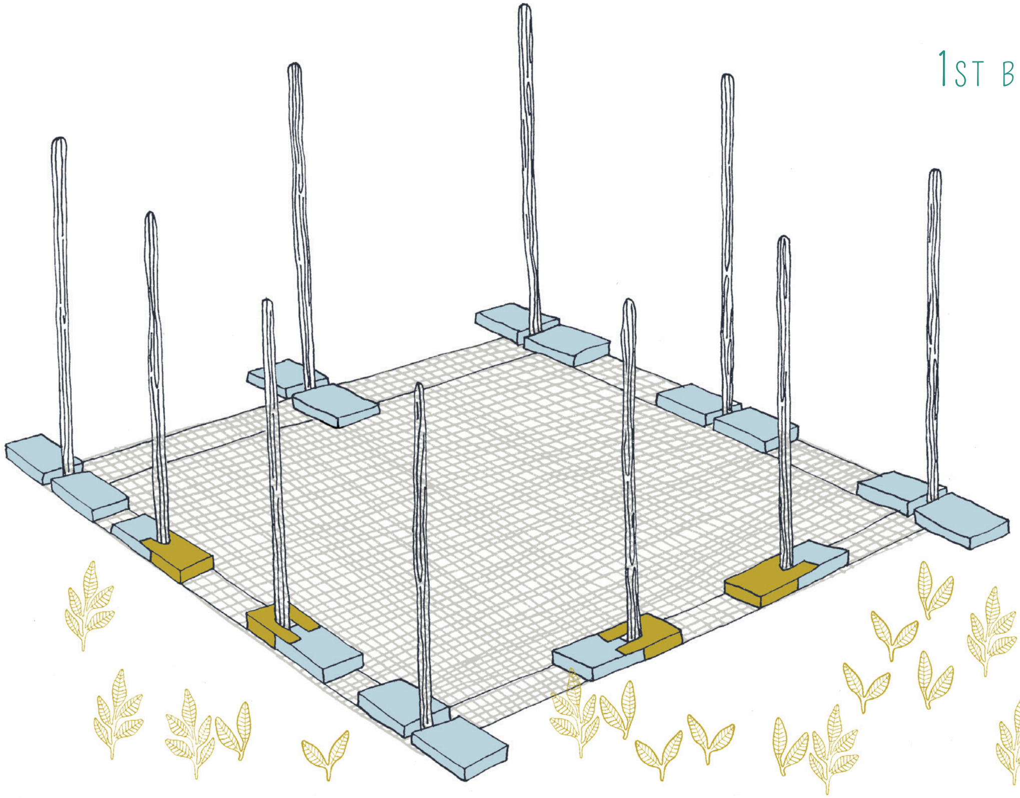
Place 60 cm [24"], 40 cm [16"]
and 30 cm [12"] long bags on the lower
part of the plinth seismic band
in order to reach a global horizontal plane
above the seismic band as shown
on the drawing.

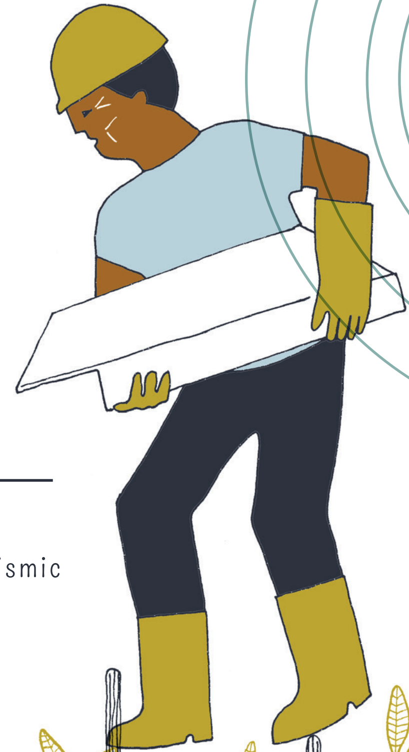
Place 60 cm [24"] long bags
at the base of the vertical poles up
to the height of the plinth seismic band.



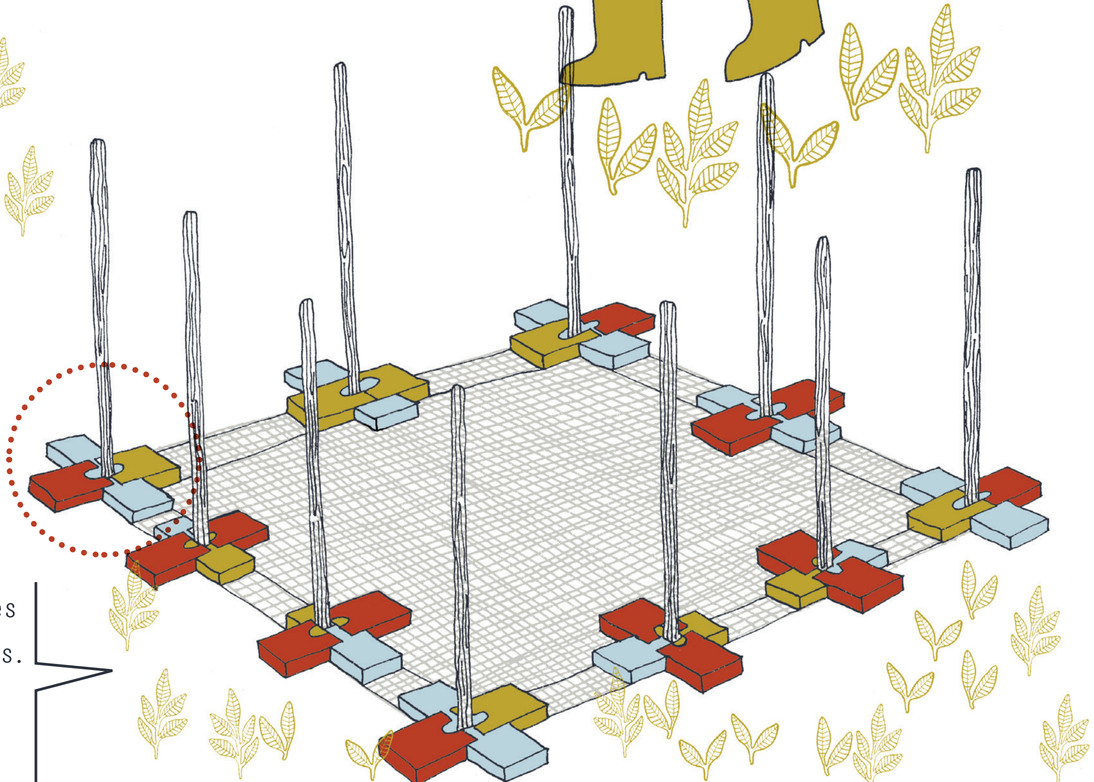
Construction

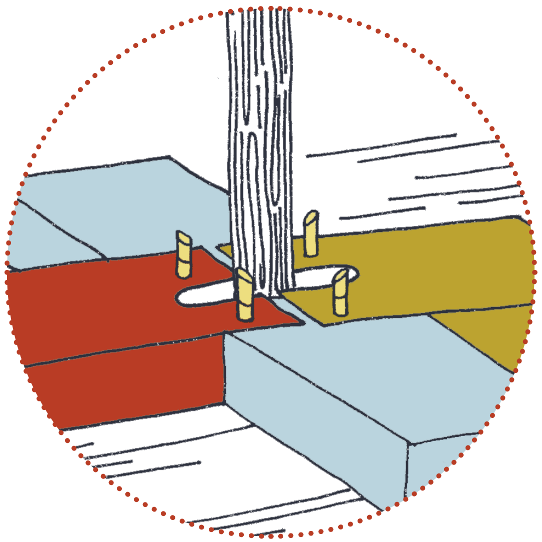
1st bag layer





Place the various size bags (various colors) above the seismic band to achieve the 1st layer.

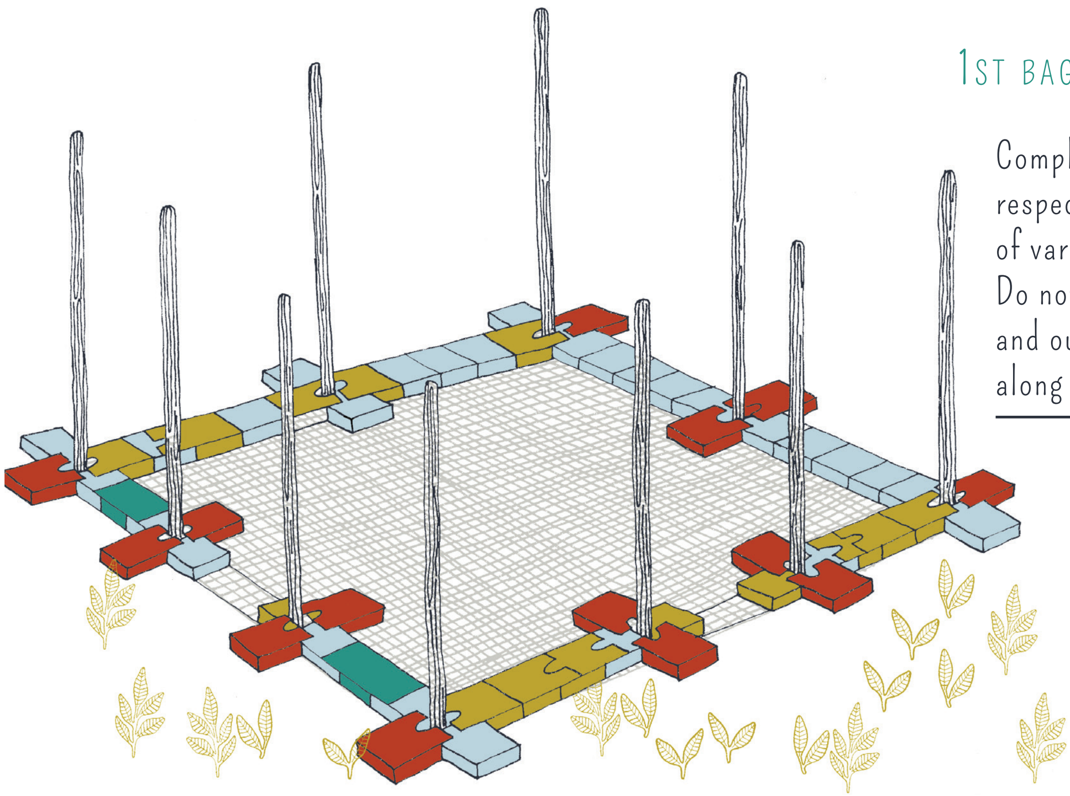




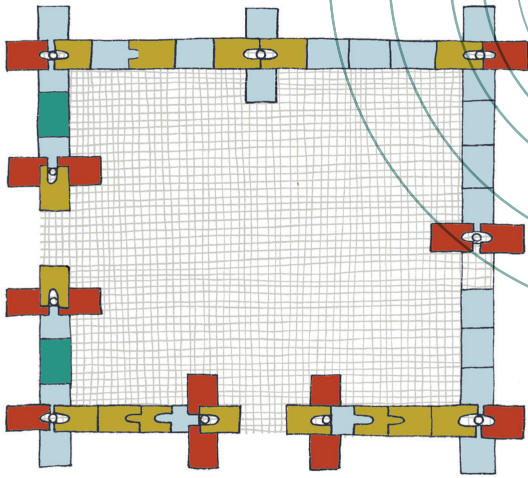
Watch out ! Bag tongues pass over the "full" bags. Crash the peaks of cut bamboo cut in bags for linking filled bags.

Construction of walls

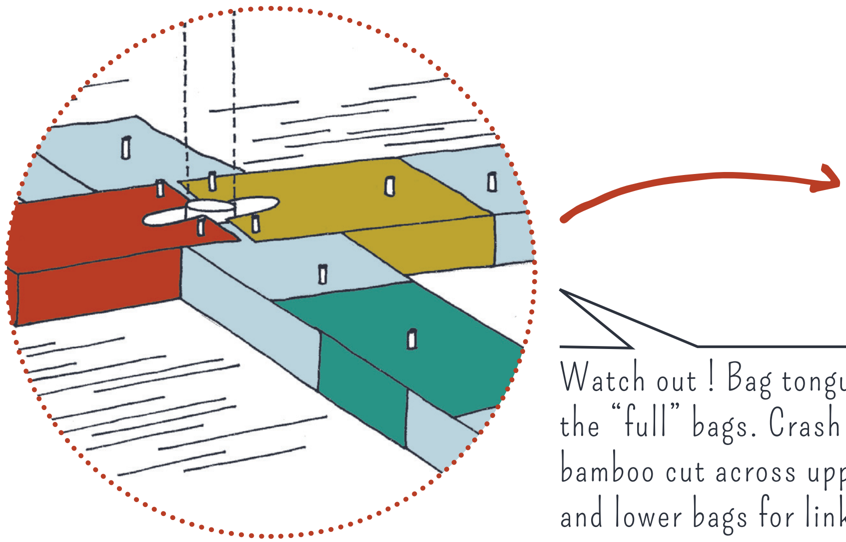
1st bag layer

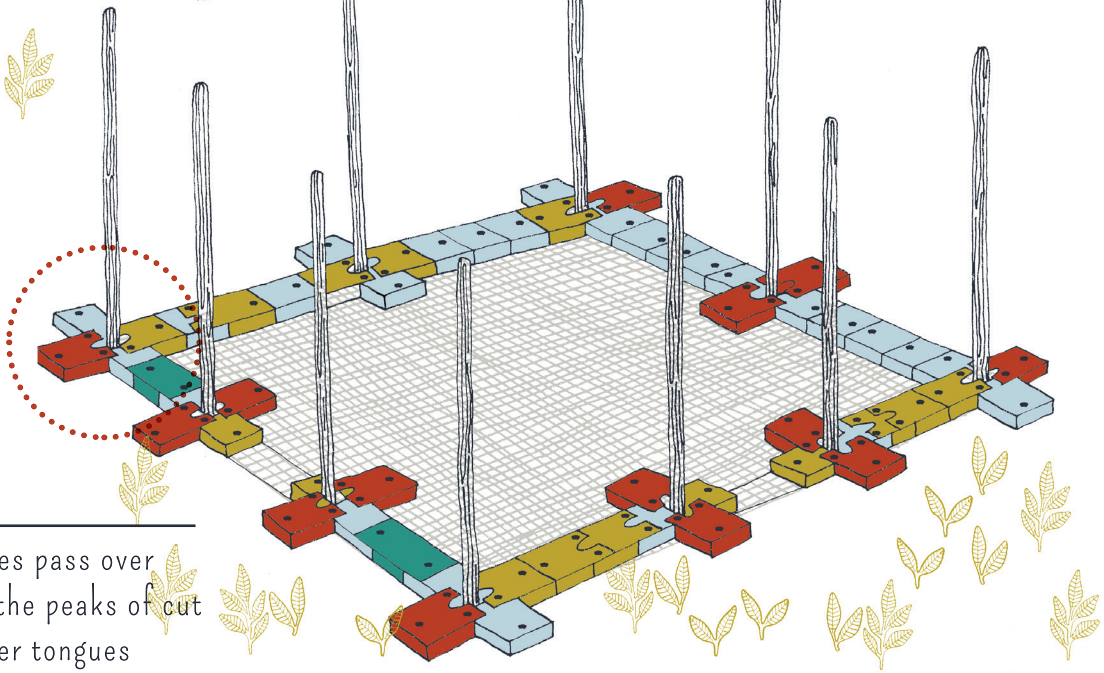


Complete the 1st layer by respecting the distribution of various bag sizes (colors). Do not forget the internal and outer strengthening along vertical poles.



1st bag layer seen from above

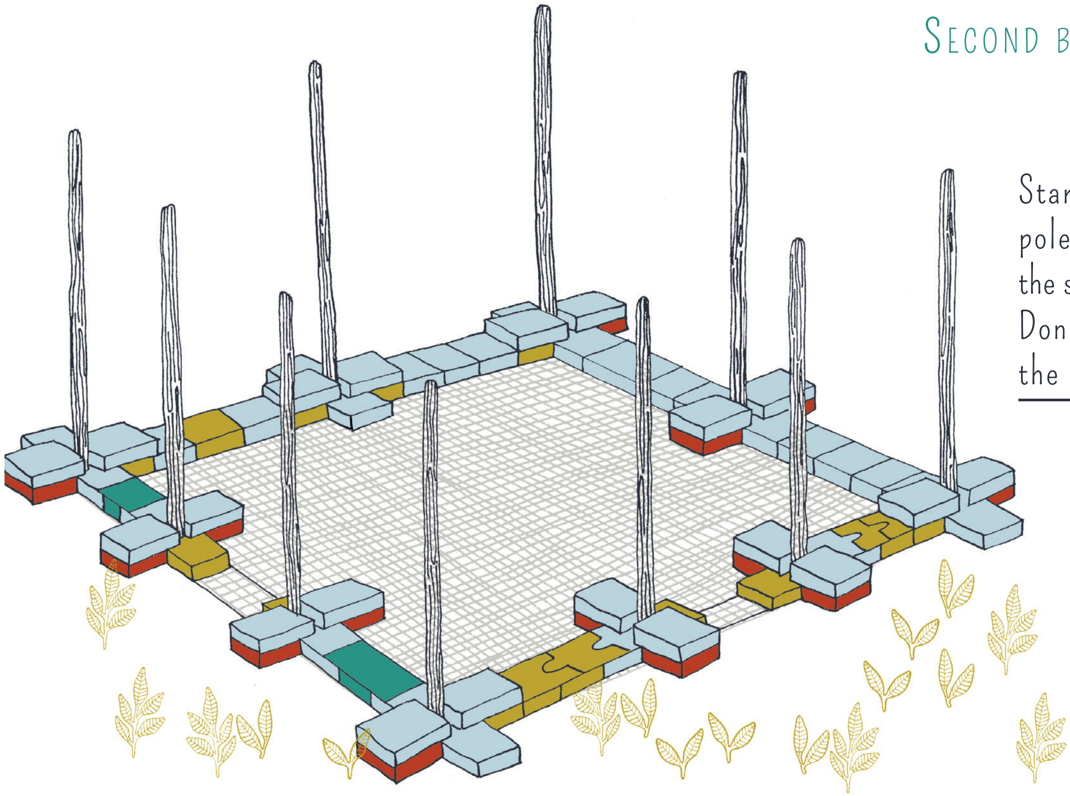




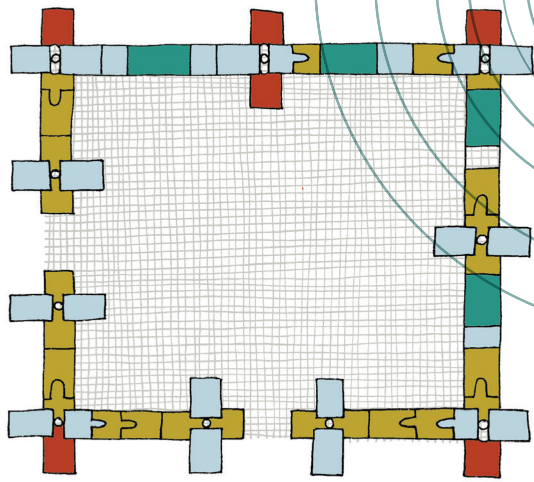
Watch out ! Bag tongues pass over the "full" bags. Crash the peaks of cut bamboo cut across upper tongues and lower bags for linking filled bags.

Construction of walls

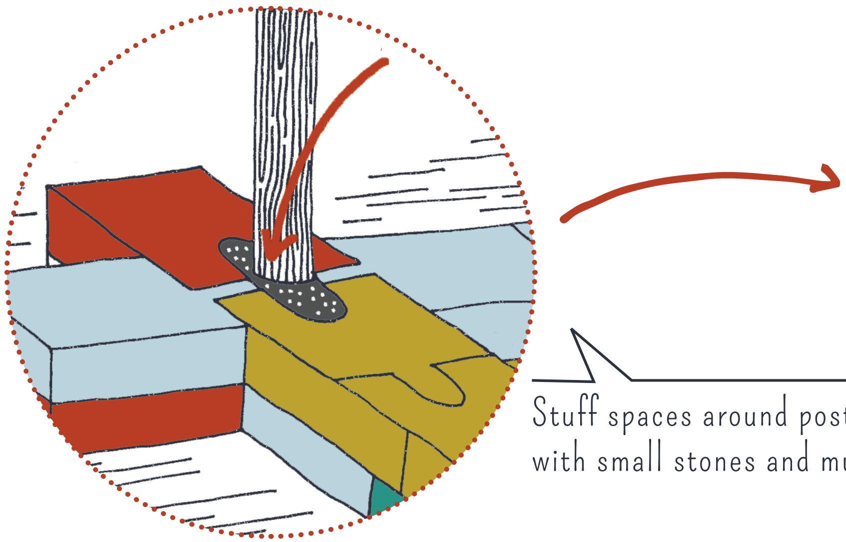
Second bag layer



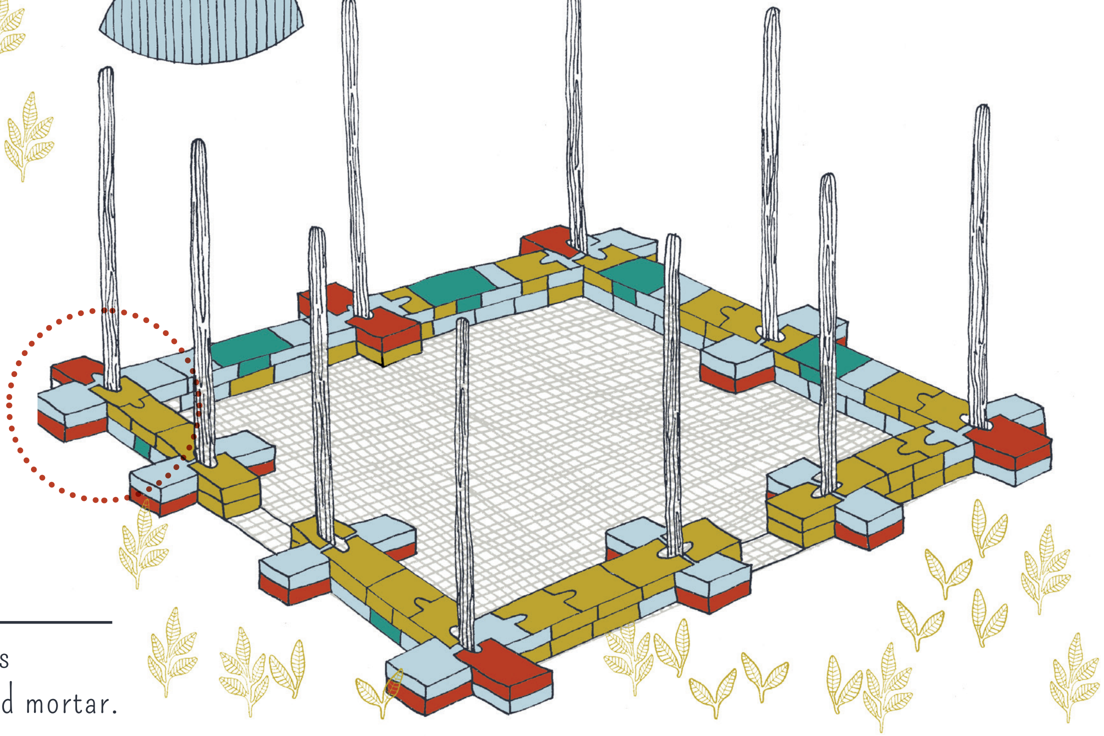
Start again by bags against poles and respect as well the sense of bag arrangement. Don't forget to crash the peaks of cut bamboo.



Second bag layer seen from above

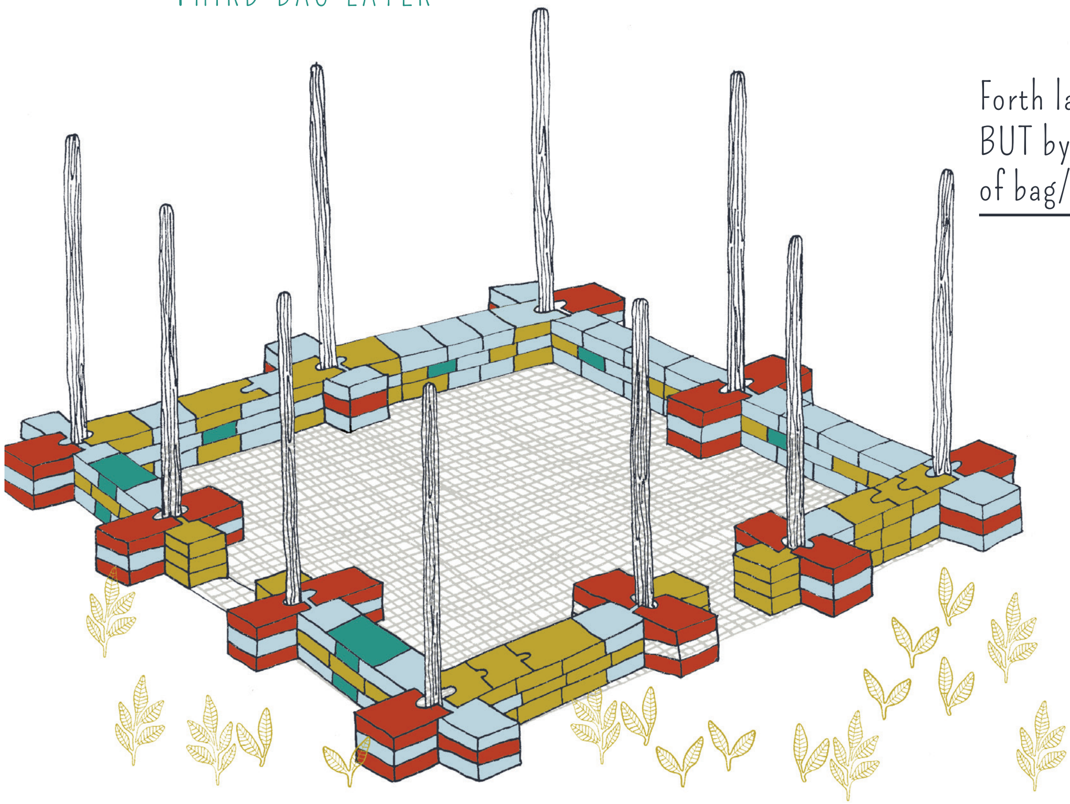


Stuff spaces around posts with small stones and mud mortar.

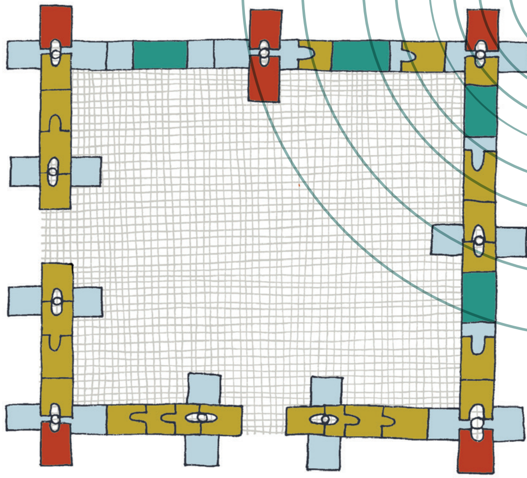


Construction of walls

Third bag layer

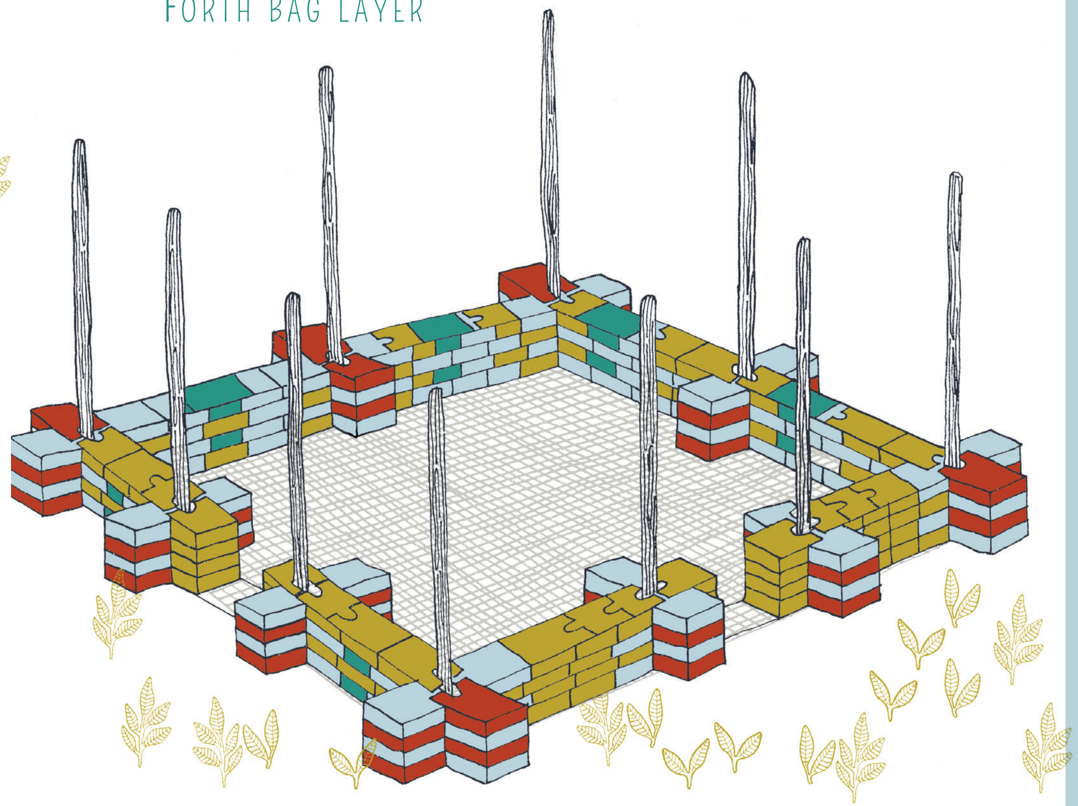


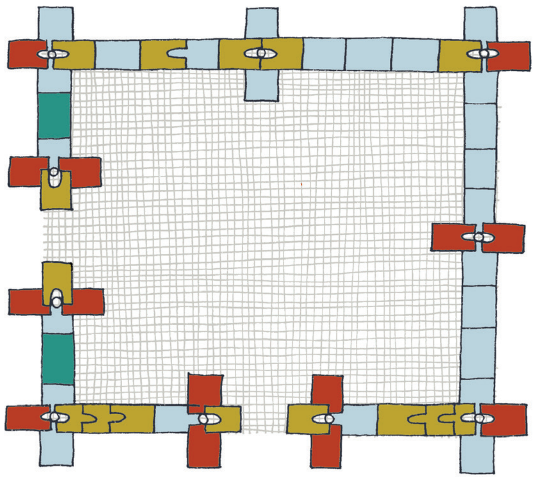
Forth layer similar to the second one BUT by inverting the sense of bag/tongue arrangement.



Forth layer from above

Forth bag layer



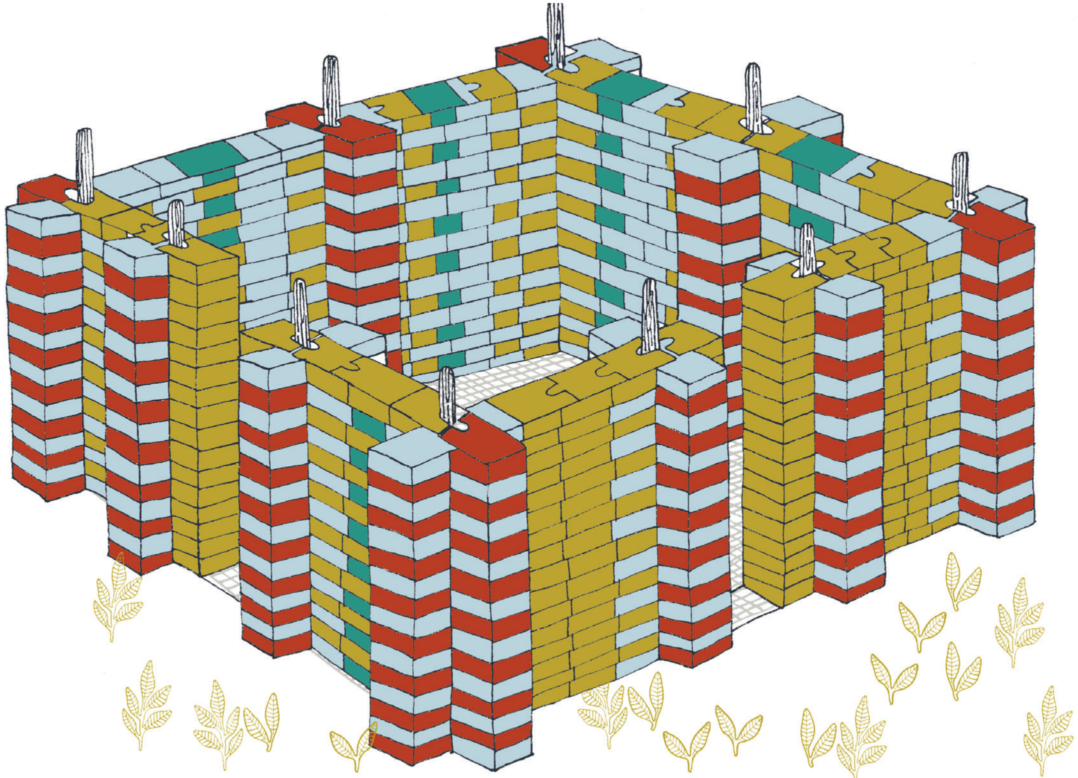


Third layer from above

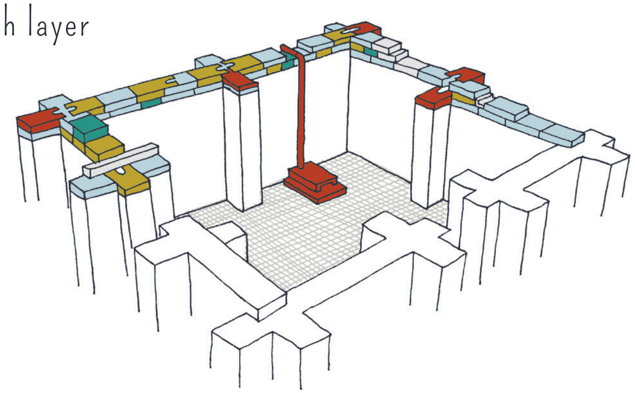
Third layer similar to the first one BUT by inverting the sense of bag/tongue arrangement.

Construction of walls

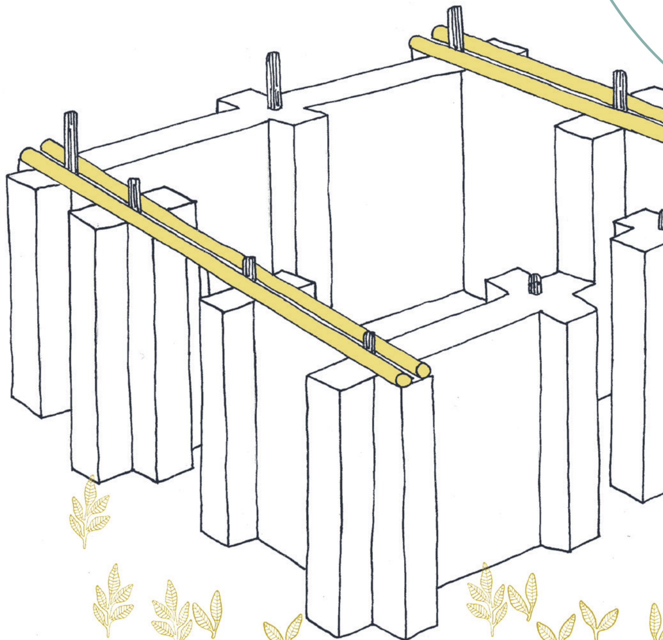
Next bag layers



Layers 5, 9 and 13 similar to the first layer
Layers 6, 10 and 14 similar to the second layer
Layers 7, 11 and 15 similar to the third layer
Layers 8, 12 and 16 similar to the forth layer



Lintel seismic band implementation



As previously mentioned, seismic bands hold the walls together and ensure integral Box action. As for the plinth band (plate 35), this lintel seismic band is made of double bamboo, 10 cm [4"] in diameter, at the top of each wall. Start with two opposite walls.

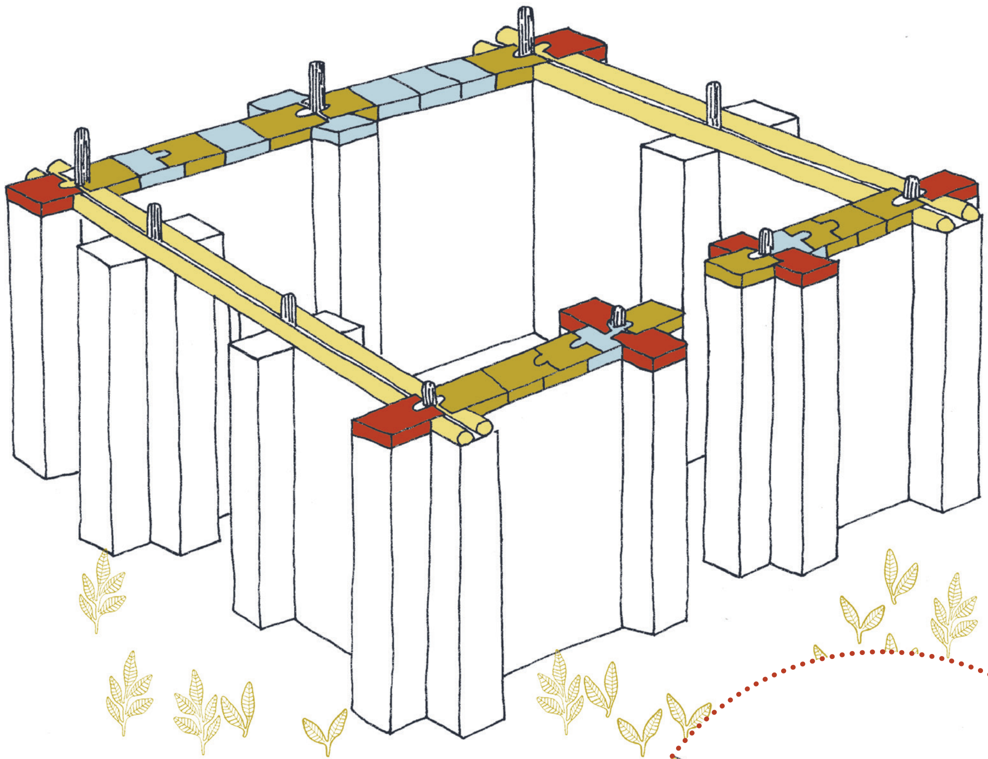
Placing of the flue

Attention not to leave the flue against PVC bags: keep it away using with stones or/and clay.

Construction of walls

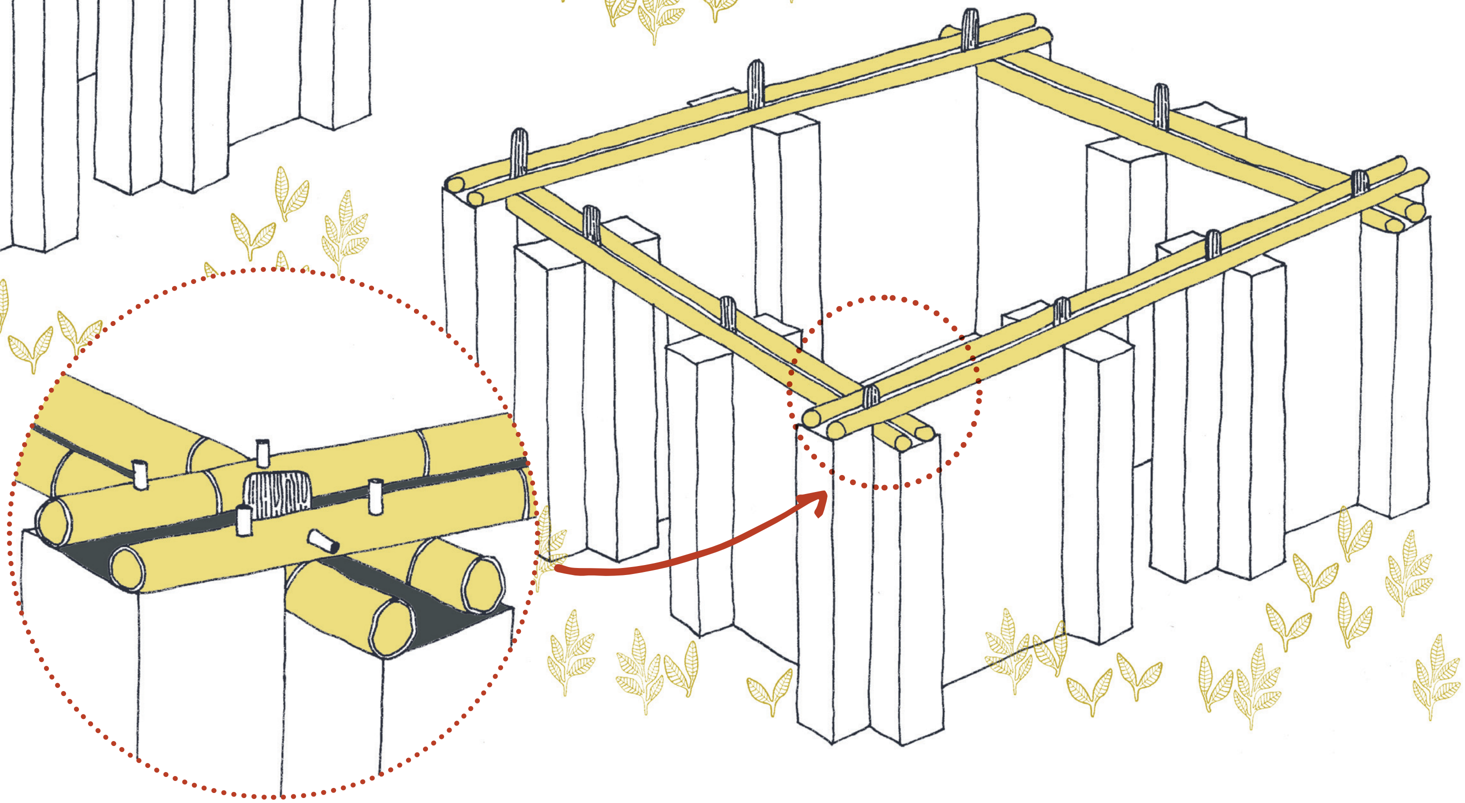
Lintel seismic band implementationwalls

Reach a global horizontal plane before placing bamboo on the two remaining opposite walls.



Before placing the seismic band bamboo on the two other opposite walls, arrange 40 cm [16”], 45 cm [18”] and 60 cm [24”] long bags on the top of the walls as shown on the drawing.

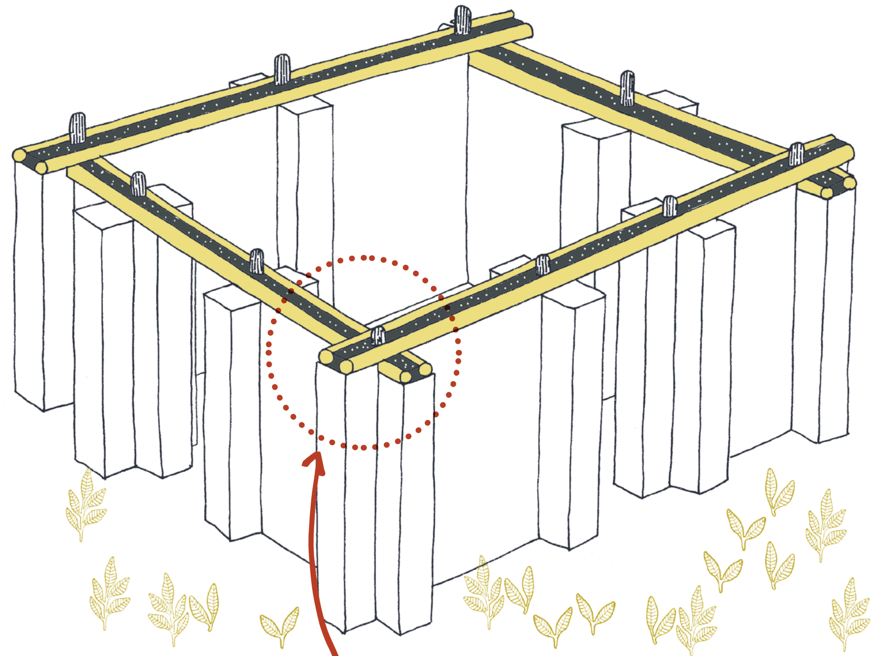
Complete the lintel seismic band

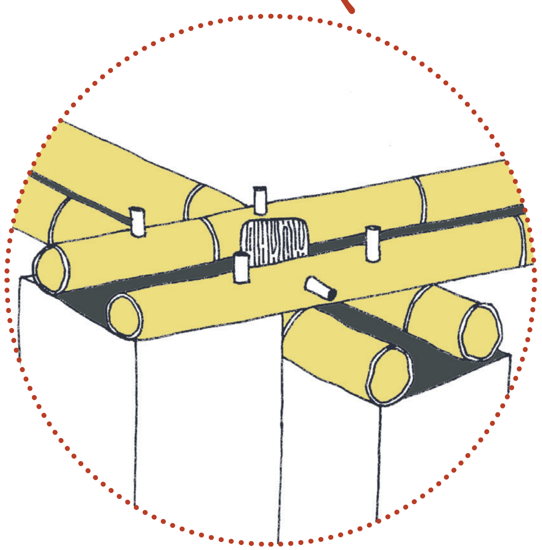


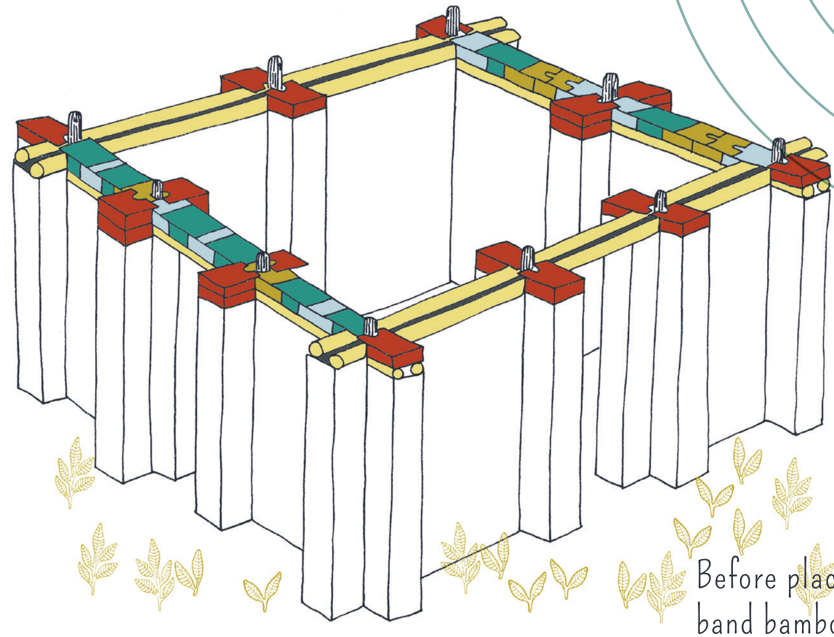
At each wall corner, bamboo are closely are closely connected (i) some with the others and (ii) with vertical poles by means of cleats.

Construction of walls and connections for roof

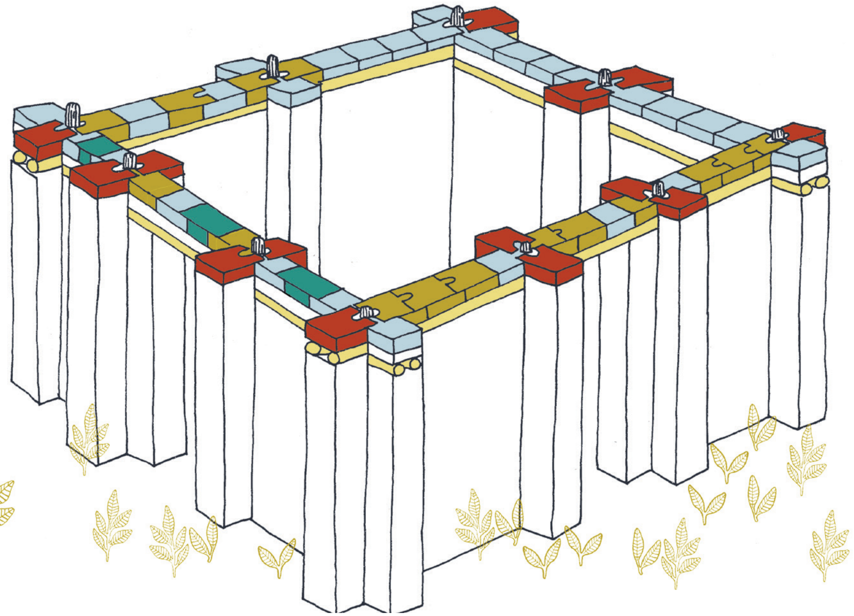
Infill the space between bamboo with small stones and mud mortar





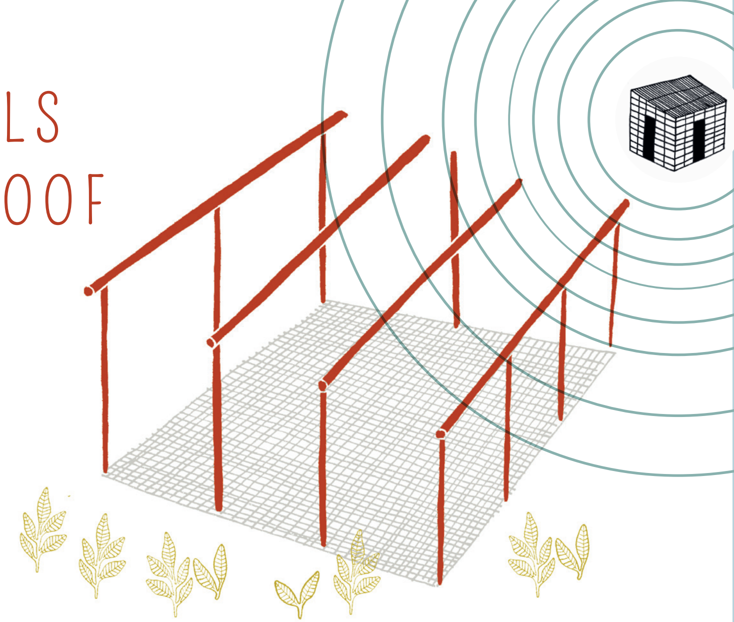


Reach a global horizontal plane

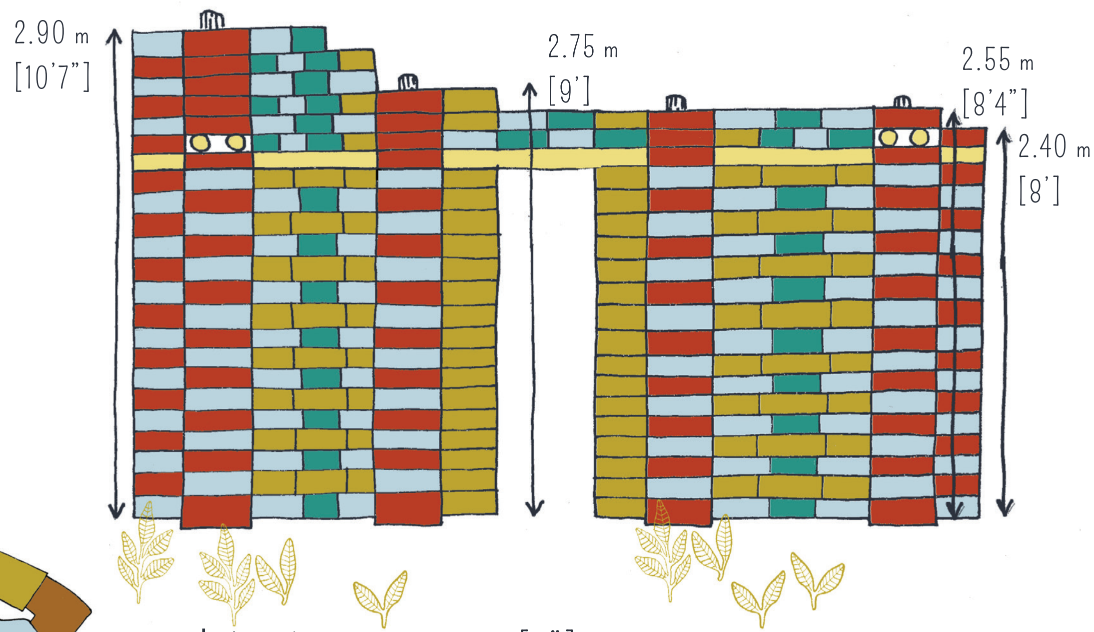


Before placing the seismic band bamboo on the two other opposite walls, arrange 30 cm [12"], 40 cm [16"] and 60 cm [24"] long bags on the top of the walls similarly to first bag layer (as shown on the drawing).

Construction of walls and connections for roof

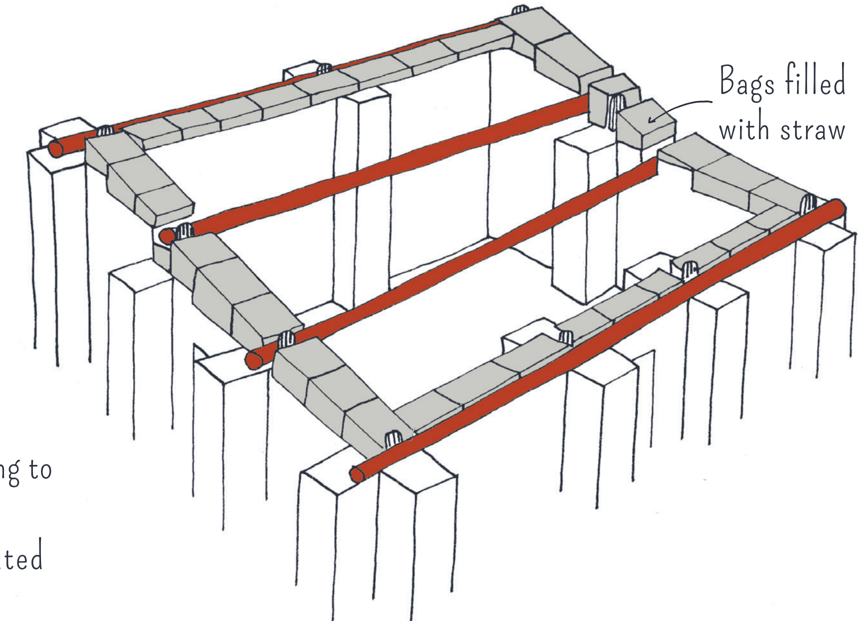


Bag layers above the lintel seismic band



Place bags up to 10 cm [4"] from the top of poles. Respect the same arrangement than for first, then second, then third, then forth layers.

Place the roof framework

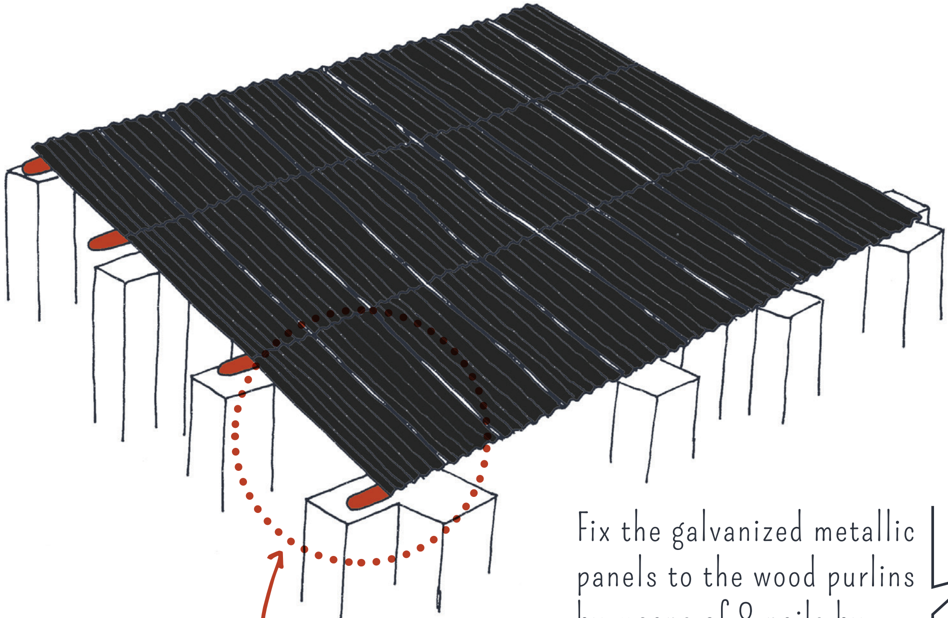


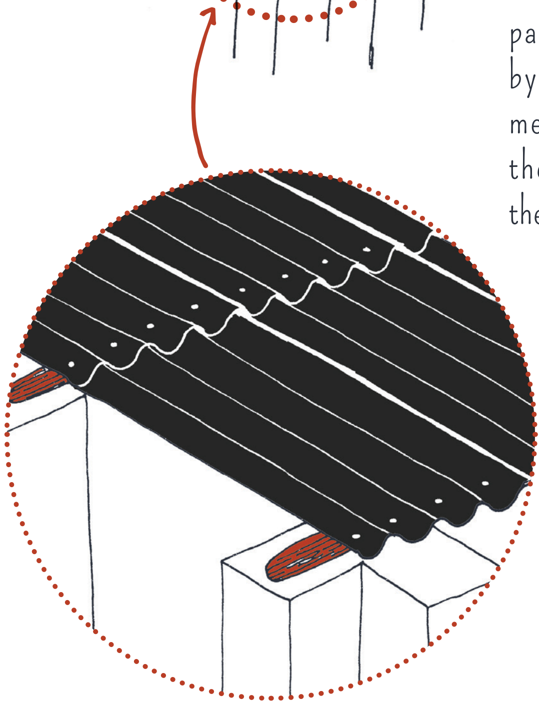
Lay down the 4 (or plus) wood purlins lintels (according to snow effects): be care that the two central one are located at the center beneath the overlapping of the galvanized metallic panels.

Connect the purlins to the poles with cleats and/or wedge them with bags of adequate sizes. Isolate and seal with bags filled with straw.

Construction of roof

Roof implementation

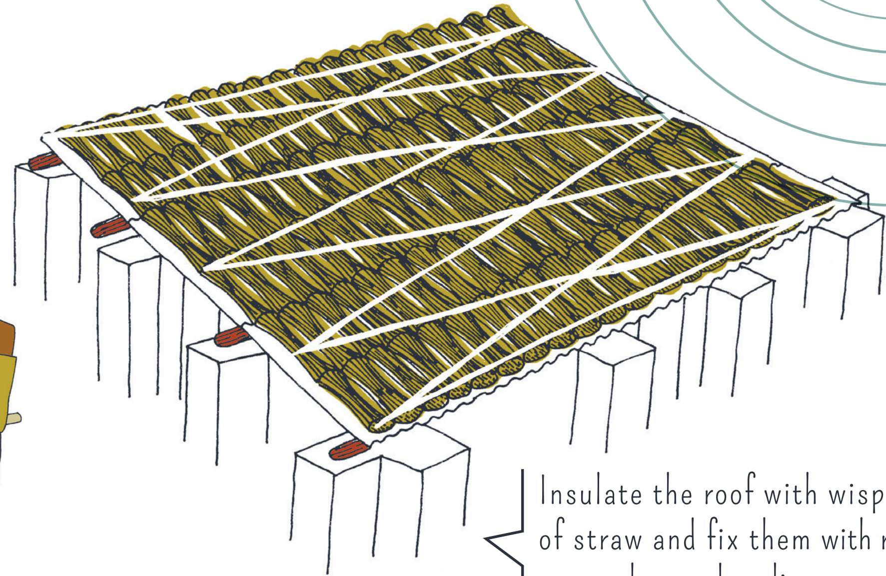




Fix the galvanized metallic panels to the wood purlins by means of 8 nails by metallic panels, 4 at the top and 4 the base of the metallic panel overlapping.

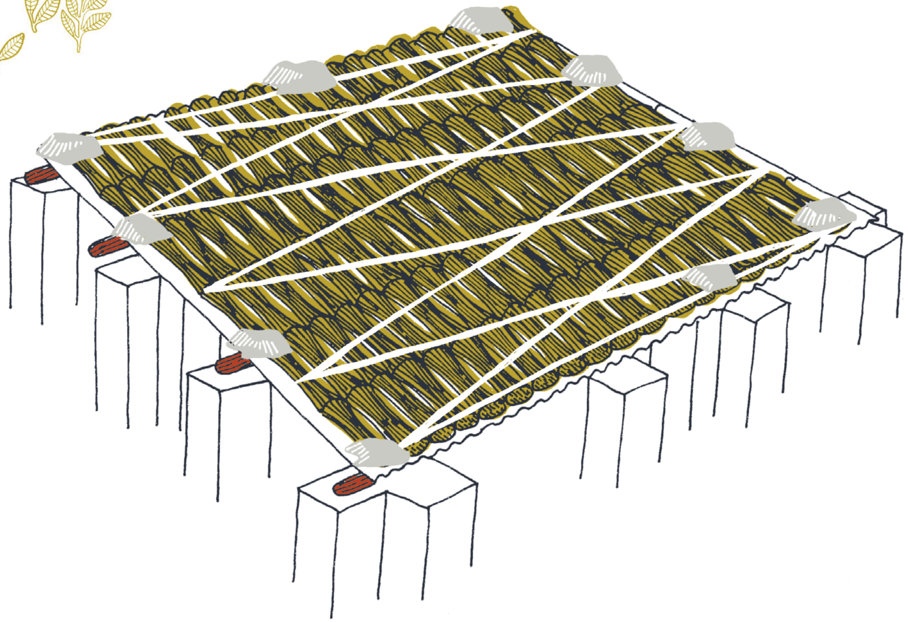
Stones are added stabilize roof against wind.

Insulation of the roof



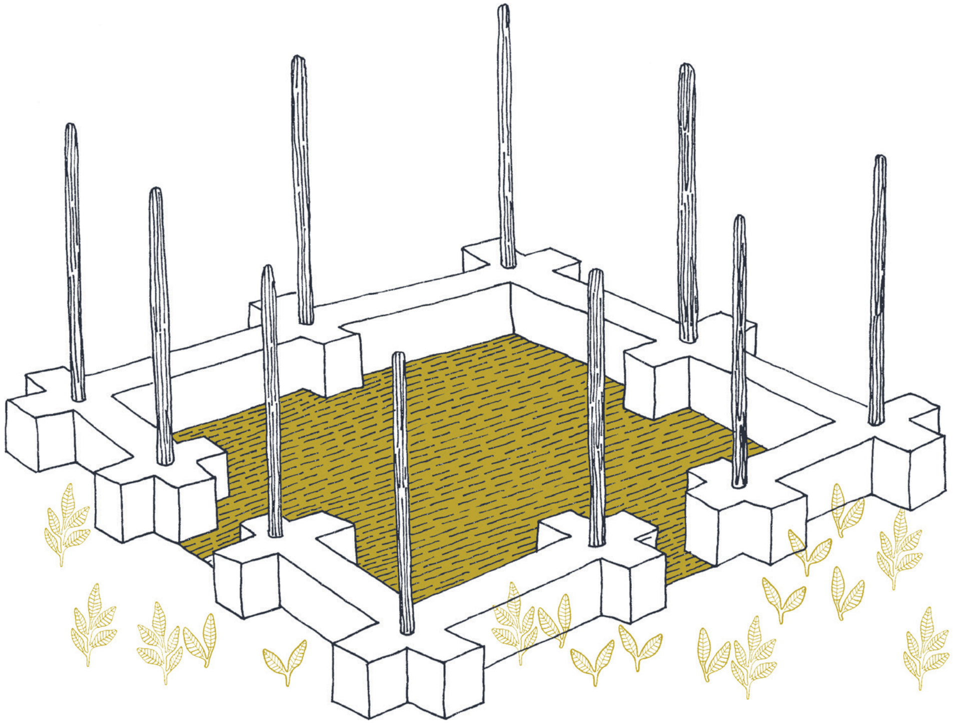
Insulate the roof with wisps of straw and fix them with rope set on the wood purlins.

Roof stabilization



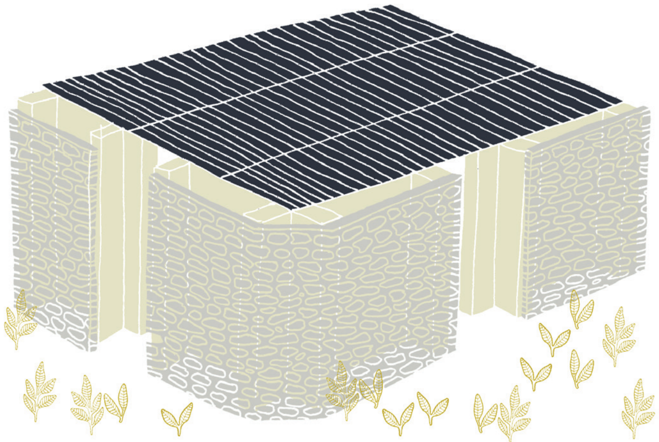
Construction of current slab

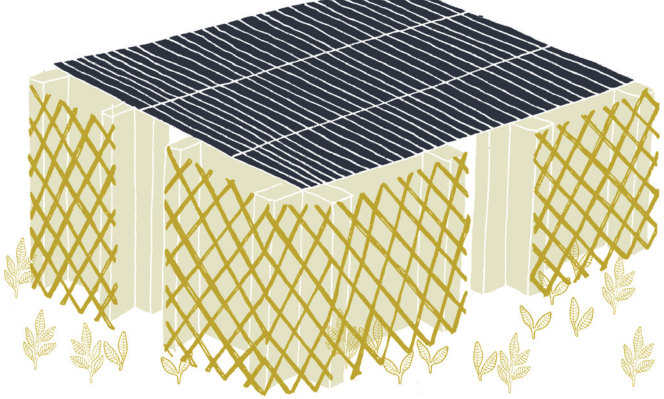
Inside the house,
settle a mud floor
about 10 cm [4"]
thick.



To protect PVC bags from the sun and guarantee the building durability, it is recommended to implement an outside facing on facades using :

- Either "dry" stones and not connected to the building façade
- Braided bamboo : but avoid the mixture clay / straw mixture which remains fragile facing rains





Prepared by

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