04

Supporting Information

Content for this chapter is still under development.
Some raw information is included here to give an idea of the type and level of detail that will be included

Specification: Bamboo

Condition
Straight pieces of bamboo should be used, any bending and curvature will affect the bamboos ability to take load.

- Split or cracked bamboo should be rejected, which similarly affect the bamboos ability to take load.
- Bamboo showing signs of beetle or termite attack should be rejected
- Bamboo should be mature at point of harvesting (>/=four years old)

Season the bamboo by allowing it to dry naturally for 2-3 months in a covered and protected area, elevated above ground, and allowing natural ventilation around and in-between the culms (Liese & Kumar, 2003; Kaminski et al., 2016c).

All storage of bamboo should be above ground and protected from the rain, and with ventilation allowed between culms. (Liese & Kumar, 2003)

Treatment
Red oxide paint and Mobil oil should be avoided

- Whilst painting/coating in mobil oil gives some level of protection, since the coating only reaches the outer layer of the bamboo it is limited in it’s effectiveness
- It’s effectiveness is further diminished by the fact that bamboo expands and shrinks which will crack the layer of protection, allowing access for beetles, termites and water.
- Mobile Oil is a known carcinogen, with risks during application, use, and disposal. Risks are to workers, house occupiers, and the wider community if it reaches the ground, drinking water, crops, or if burnt the air.

Soaking bamboo in water washes out some of the starch, making the bamboo less attractive to beetle attack. It has no effect however on its susceptibility to termite and funghi attack.

The water treatment method can be improved with the following:

- Break the nodes of the culms, or drill two holes into each internodal region, to allow water to enter the centre of the culm.
- Ensure the culms are submerged completely.
- Submerge the columns for long periods, ideally 6-8 weeks. (Liese & Kumar, 2003)

Boron Treatment
Boron is one of the few good treatment methods for bamboo.

Boron is a non-toxic safe to use chemical which protects effectively against beetles and termites.
It is possible for treatment to be cost effective, with examples of it being done for a 20-50% cost increase compared to untreated bamboo, however because of the relative cost and complexity associated with treatment with boron, it is better suited to a centralised facility, as oppose to treating on a household level.

For further information on bamboo, refer to Design Guide for Engineered Bahareque Housing, IStructE Structural use of bamboo Parts 1-4, and the Humanitarian Bamboo Guidelines, humanitarianbamboo.org

Specification: Stabilised and non stabilised earth construction

Minimum Strength:
Non-seismic: 2.5N/mm2
Seismic: 5N/mm2

Mix
Suitable soils must be used for earth construction. Mix (proportion of clay, sand and where required cement or lime) to be determined by trial and testing. For details on the mixing process, see Further Information, Soil preparation.

The suitability of soil for unfired earth blocks (whether stabilised or not) may be determined through a variety of tests. Some may be carried out in the field with no equipment at all while others are expensive lab tests. The aim typically is to determine:

1. Composition (gravel/sand/silt/clay)
2. Plasticity
3. Optimum moisture content
4. Organic matter content, which should always be removed for earth construction.

Details of simple field testing, such as the jam jar test, can be found in the 'Lime Stabilized Construction, A Manual and Practical Guide' by Strawbuild.

Stabilised
The following table details soils which are unsuited to block making and should be avoided

Table 5. Soil unsuited to block making (*HB195-2002* [7]).

Cement-stabilised	Topsoils Organic matter content greater than 1% to 2% Highly expansive soils Soils with soluble salts in sufficient quantities to impair strength or durability (found by trial testing).
Lime-stabilised	Topsoils Soils with combined clay + silt content less than 30% Organic matter content in excess of 20% Soils with excessive sulphates.

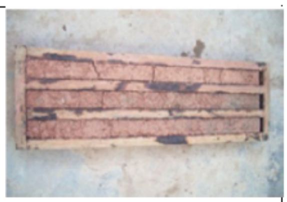
Lime Stabilised
Lime stabilisation requires trial and testing to achieve. A shrinkage test can be used to determine initial suitability, with shrinkage between 10 and 60mm indicating a suitable soil.

The table below details suitable soil composition. The 'Lime Stabilized Construction, A Manual and Practical Guide' by Strawbuild offers more detailed information and should be consulted when undertaking earth stabilisation.

Lime stabilisation		
	Australian earth construction, lime stabilisation	Auroville, compressed earth blocks, lime stabilised
%fine gravel	5-70%	15
%sand		30
%silt	10-60%	20
%clay	20-60%	35

Cement Stabilised
For cement stabilised blocks, a linear shrinkage test can also indicate the correct cement quantity, with further trial and testing required

Gap	Mix ratio		
	Soil	Cement	%
Less than 15mm	Too much sand — add clay		
15 - 30mm	16	1	6.3%
30 - 45mm	14	1	7.1%
45 - 60mm	12	1	8.3%
More than 60mm	Too much clay — add sand		



RedR – engineering in emergencies

Suitable soil composition is detailed in the table below.

Cement stabilisation		
	Australian earth construction, cement stabilisation	Auroville, compressed earth blocks, cement stabilised
%fine gravel	45-80%	15
%sand		50
%silt	15-30%	15
%clay	up to 25%	20

Specification: Stabilised and non stabilised earth block making

Soil preparation

1. Dry the soil
2. Crush the soil.
3. Pass soil through a 5mm or 6mm sieve to remove larger stones
4. Depending upon the grading of particles in the soil, additional clay/sand/ gravel may be blended in.
5. If required, mix stabiliser until mixture is all the same colour. This is generally done by volume. It is best done in relatively small batches to ensure consistency and thorough mixing.
6. Water should be mixed gradually and thoroughly by hand. The amount required is likely to vary, but 10%–15% by volume may be used as a starting point. Dropped from shoulder height, the mixture should break into two or three pieces. If it crumbles it is too dry. If it is too wet it will remain as one piece. Concrete mixers are not suited to soil mixing as the soil will stick within the sides and not mix properly.
7. Mixing time should be at least eight minutes.
8. “Holdback time” between mixing and block production should be kept below one hour at the most where soil is cement-stabilised, as strength can reduce. Where lime is used, strength may increase with holdback time.

Block size

Stabilised blocks to be 14”x 6.5” x 6.5”

Unstabilised blocks to be 14”x 6.5” x 3.25”

This means the unstabilised blocks will be lighter, and the two blocks can be easily indentified.

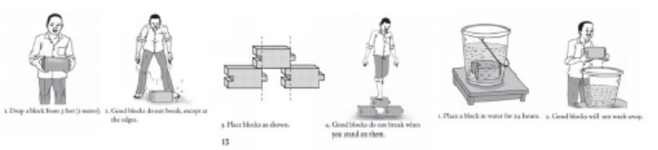


Fig xx.
Rudimentary block tests: (L) drop test; (C) bending test; (R) durability test (T4T machine operation manual [43]).

Curing

Unstabilised
It is important that earth blocks are not allowed to dry out too quickly as this may cause cracking.

Blocks should be raised up or placed on plastic sheet to prevent loss of moisture to the ground.

Blocks should be covered over with plastic sheet or cloth to prevent evaporation and protect against rain.

Stabilised
Like concrete, earth construction gains strength with age.

It is important that earth blocks are not allowed to dry out too quickly as this may cause cracking.

Blocks should be raised up or placed on plastic sheet to prevent loss of moisture to the ground.

Blocks should be covered over with plastic sheet or cloth to prevent evaporation and protect against rain.

Blocks should be kept damp for several days by sprinkling with a watering can or similar.

Blocks may initially be stored flat before being stacked into piles.

Blocks stabilised with cement should be cured for a minimum of 14 days, ideally 30 days.

Blocks stabilised with lime should be cured for at least 30 days.

Field testing

Field testing should be undertaken for each batch of blocks made.

Blocks should survive a drop test and a bending test. Stabilised blocks should also survive a bucket test.

Mortar

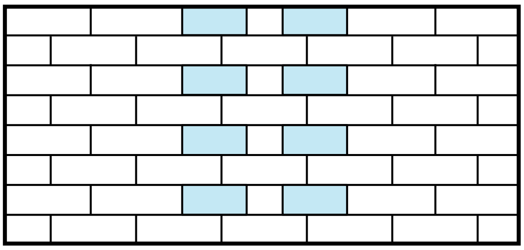
Use the same mix as for blocks. For stabilised blocks, use stabilised mortar, for unstabilised blocks use unstabilised mortar.

Mortar beds = 0.5”

Specification: Block laying

Correct block laying is required to achieve strength of the wall.

The brick bond used for the wall ensures that vertical joints in consecutive courses do not align, and are a minimum of a quarter of a block length apart.



Elevation

Walls should be fully bonded at returns and corners.

Slushing, where mortar in vertical joints is laid after the block has been placed, should not be done, as this prevents the vertical mortar from being compressed as the block is laid.

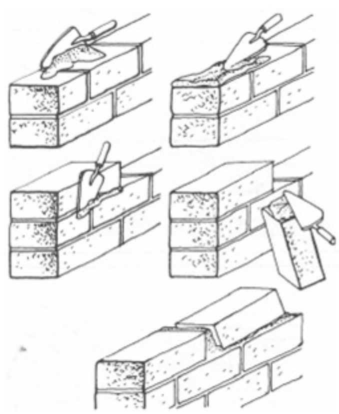
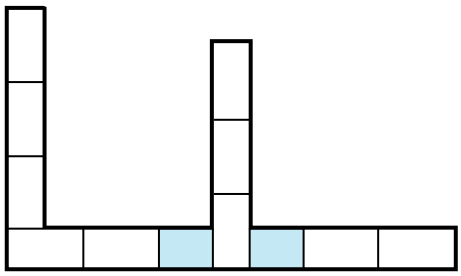


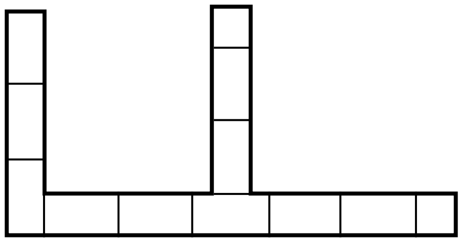
Fig xx.
Vertical mortar applied to block so that it may be compressed as the block is laid (Houben and Guillaud [1]).

All blocks to be cleaned and wetting before mortar is applied

Mortar should not dry out before bricks are positioned, so do not spread it out more than 5 bricks at once.



2nd course



1st course

Mortar should not be too wet, else it will shrink and crack.

Specification: Concrete

Minimum concrete strength to be 21MPa (Pakistan building code).

30Mpa can be achieved with the following mix,

Mix
Ordinary Portland Cement: Sand: Aggregate = 1:2:4

For non-structural concrete (ie for blinding) the mix may be adapted to save cost, such as 1:4:12

Concrete to be thoroughly mixed for at least 5 minutes.

The cement, sand, aggregate and water must be evenly distributed throughout once mixing is complete. The mix should be a uniform colour.

All concrete should be thoroughly compacted in order to release trapped air bubbles because air pockets weaken the concrete.

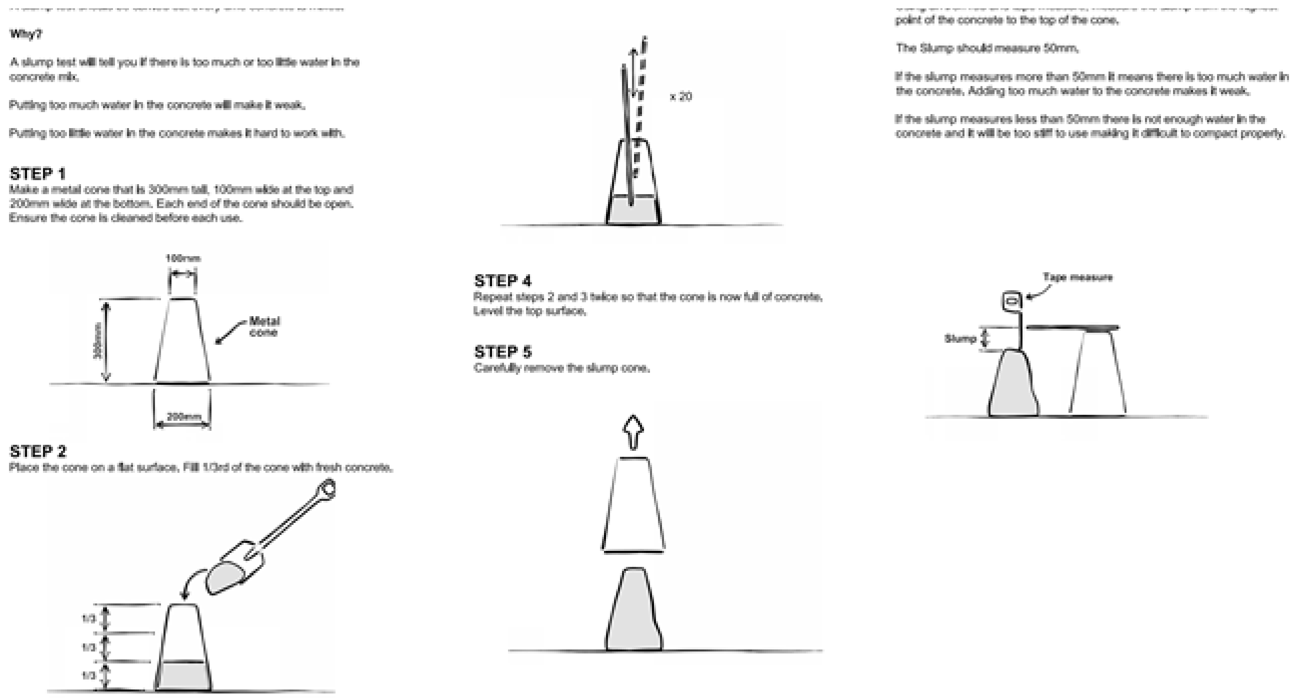
Concrete curing
Concrete should not be allowed to dry out too quickly. This is to prevent cracks resulting from the surface drying out faster than the inner concrete.

Proper curing enables concrete to achieve its full strength and durability.

After it is poured it should be protected from direct sunlight. It should be covered with plastic sheet/ cements bags or similar and watered for up to 7 days.

After 7 days the concrete will have achieved 2/3 of its design strength.

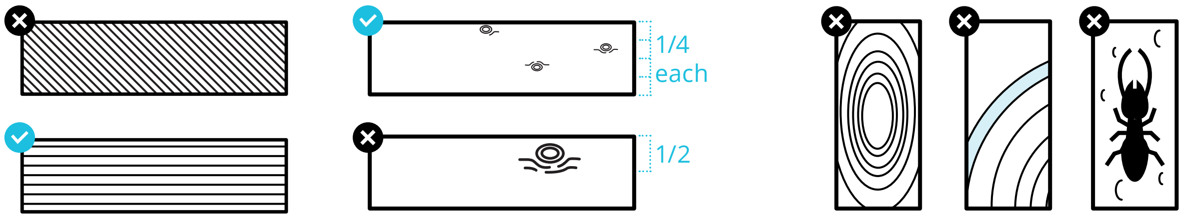
Concrete testing
A slump test should be performed for each concrete mix to ensure the correct consistancy. Too much water commonly decreases the strength of concrete, a slump test helps to avoid this occurance.



Specification: Aggregate

- Stone aggregate should be used if available.
- Crushed angular gravel is preferred.
- Avoid rounded river gravel.
- Aggregate should be washed and clean, free of organic material/sand/silt/clay.
- Sizes evenly distributed between 5 and 20mm.
- Long thin shards of angular gravel should be discarded. (They will not compact as well and increase the likelihood of air pockets in the concrete.)
- If no stone aggregate is available, crushed burnt brick can be used.
- Brick has a lower compressive strength than stone. When used as aggregate it will therefore give concrete of lower strength.
- Ensure that brick has been fired evenly throughout.
- Sizes evenly distributed between 5 and 20mm.
- Long angular shards of brick to be discarded.
- Crushed brick should be soaked in water prior to being added to the mix. This is to reduce the amount of water that the porous brick leaches out of the mix.

Specification: Timber



- Extra care must be taken when selecting the timber for the trusses
- The timber should be 'dry'. Timber that has not been properly dried is more likely to be bend and to split
- Timber should be as straight as possible and should have no large splits
- All timber should be stored and covered in neat stacks to prevent warping

Sloping Grain
The grain of the timber should be straight. Sloping grain is not allowed. Timber with sloping grain is weak.

Knots

- Knots are weaknesses in timber
- Timber with a lot of knots is not allowed
- Small knots that are less than 1/3 of the width of the timber are allowed
- When joining one piece of timber to another make sure that there are no knots near to the connection

Boxed heart

- The piece of timber that is cut from the very middle of the tree is known as boxed heart
- This piece of timber will split easily and is therefore weak

Sapwood

- Timber cut from the edge of the tree trunk is not allowed

Termites

- Timber that shows signs of termites or any other insect attack is not allowed

Specification: Damp proof membrane

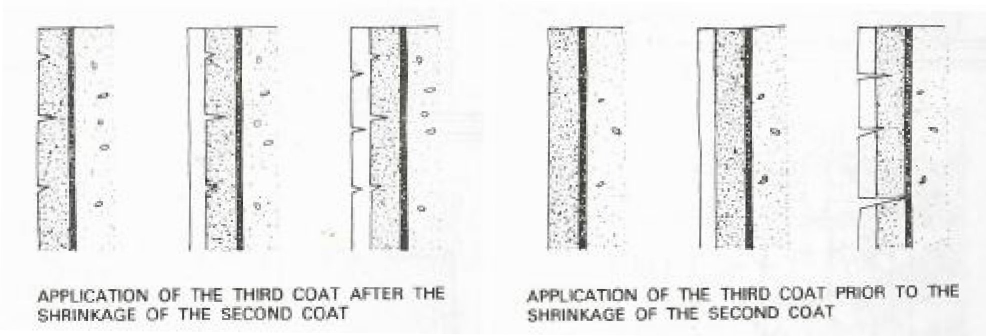
Damp proof membrane
Use a large, thick (thickest that is available) plastic sheet.
300mm lap length at all joints Joints to be sealed top and bottom with heavy duty waterproof tape.
Sheet to be inspected for any rips or tears. Repair to be carried out with suitable heavy duty waterproof tape.

Specification: Render

Render
Render should be applied in layers to allow for shrinkage.

Maintain a good bond between layers of render by roughening the previous layer before it has set, and wetting it before applying a new layer.

Keep render layers to a maximum of 0.5” thick



HOUBEN, H and GUILLAUD, H. Earth construction: a comprehensive guide. ITDG, 1994.

Stabilised Render
For details on the stabilisation mix, see Specification: Stabilised and non stabilised earth construction.

Ensure that render is cured, see Specification: Stabilised and non stabilised earth block making, curing.

Cement Render
See Specification: Concrete, non structural concrete and concrete curing

Cost: Financial & Carbon

Assumptions & Estimates

This section includes the cost assumptions and estimates used to evaluate the recommended design components (five foundation types, five wall types, and three oof types). Cost includes the capital financial cost of each component and the capital carbon cost of each component. The assumptions underlying these estimates are included where relevant so that users can compare and make adjustments where necessary. It's important to note that these estimates are merely estimates. They were developed in order to compare the relative costs of each component and outline design. These estimates should not be relied on to develop programme budgets or construction costs for the following reasons:

- Data are out of date. The material costs used are based on analysis of bills of quantities (BoQs) received from several shelter agencies mostly during 2016. The actual costs of these materials have presumably fluctuated since then and these estimates no longer reflect market prices.
- This is not a BoQ. The estimates are for the exact volume of materials required for each component but do not account for wastage or the lumpy nature of procurement, e.g. the exact volume of bricks are specified but bricks may need to be purchased by the tonne and there can be up to 25% breakage of materials. These issues are not included in the costs estimates.
- Labour and transport costs vary considerably. The estimates generally assume labour costs to be 20% and transport costs to be 5% of the material costs. However, this varies by location, material and situation. These variables are not included in the costs estimates.

Arup developed a detailed cost estimating model in Microsoft Excel in order to generate these estimates. Some extracts are included here for illustration. The full model can be found online here: XXX [insert link to online repository]. The user can update the excel file with specific design parameters (e.g. wall dimensions) and unit costs (e.g. linear metre of timber) in order to adapt the estimates to their designs.

									TOTAL		
Wall	Cost (PKR)	CO2 (kg)	Roof	Cost (PKR)	CO2 (kg)	Foundation	Cost (PKR)	CO2 (kg)	Cost (PKR)	Cost (USD)	CO2 (kg)
Loh Kat	15,361	569	Timber	11,410	311	Basic	3,103	377	**30,426**	**289**	**1,256**
Loh Kat	15,361	569	Timber	11,410	311	Improved	13,549	921	**40,872**	**388**	**1,800**
Loh Kat	15,361	569	Bamboo	12,071	241	Basic	3,103	377	**31,087**	**295**	**1,186**
Loh Kat	15,361	569	Bamboo	12,071	241	Improved	13,549	921	**41,533**	**395**	**1,731**
Layered Mud	22,778	1,432	Timber	11,410	311	Mud / Adobe	11,230	824	**76,141**	**723**	**2,567**
Layered Mud	22,778	1,432	Timber	11,410	311	Burnt Brick	25,975	2,927	**90,885**	**863**	**4,670**
Layered Mud	22,778	1,432	Bamboo	12,071	241	Mud / Adobe	11,230	824	**76,801**	**730**	**2,497**
Layered Mud	22,778	1,432	Bamboo	12,071	241	Burnt Brick	25,975	2,927	**91,546**	**870**	**4,600**
Adobe	18,795	971	Timber	11,410	311	Mud / Adobe	11,376	824	**42,717**	**406**	**2,105**
Adobe	18,795	971	Timber	11,410	311	Burnt Brick	25,975	2,927	**57,316**	**545**	**4,209**
Adobe	18,795	971	Bamboo	12,071	241	Mud / Adobe	11,376	824	**43,378**	**412**	**2,036**
Adobe	18,795	971	Bamboo	12,071	241	Burnt Brick	25,975	2,927	**57,977**	**551**	**4,139**
Adobe	18,795	971	Steel	14,736	390	Mud / Adobe	11,376	824	**46,044**	**437**	**2,184**
Adobe	18,795	971	Steel	14,736	390	Burnt Brick	25,975	2,927	**60,643**	**576**	**4,288**
Fired Brick	40,800	4,332	Timber	11,410	311	Burnt Brick	25,975	2,927	**78,185**	**743**	**7,570**
Fired Brick	40,800	4,332	Timber	11,410	311	Concrete	23,252	1,566	**75,462**	**717**	**6,208**
Fired Brick	40,800	4,332	Bamboo	12,071	241	Burnt Brick	25,975	2,927	**78,845**	**749**	**7,500**
Fired Brick	40,800	4,332	Bamboo	12,071	241	Concrete	23,252	1,566	**76,122**	**723**	**6,138**
Fired Brick	40,800	4,332	Steel	14,736	390	Burnt Brick	25,975	2,927	**81,511**	**774**	**7,648**
Fired Brick	40,800	4,332	Steel	14,736	390	Concrete	23,252	1,566	**78,788**	**748**	**6,287**
Concrete Block	36,863	2,363	Timber	11,410	311	Burnt Brick	25,975	2,927	**97,728**	**928**	**5,601**
Concrete Block	36,863	2,363	Timber	11,410	311	Concrete	23,252	1,566	**95,004**	**903**	**4,239**
Concrete Block	36,863	2,363	Bamboo	12,071	241	Burnt Brick	25,975	2,927	**98,388**	**935**	**5,531**
Concrete Block	36,863	2,363	Bamboo	12,071	241	Concrete	23,252	1,566	**95,665**	**909**	**4,169**
Concrete Block	36,863	2,363	Steel	14,736	390	Burnt Brick	25,975	2,927	**101,054**	**960**	**5,680**
Concrete Block	36,863	2,363	Steel	14,736	390	Concrete	23,252	1,566	**98,331**	**934**	**4,318**

Figure XX. Cost estimates (financial and carbon) for all components and outline designs

COST (PKR)	Shelter wall type				
Element	Layered mud	Adobe	Fired brick	RC block	Loh Kat
Foundations	3,003	3,222	20,424	18,282	6,103
Walling	24,616	35,037	52,845	48,288	10,046
Doors & windows	3,067	3,046	3,013	3,013	3,080
Roof	12,071	11,410	14,736	14,736	12,071
SUBTOTAL	**42,756**	**52,715**	**91,018**	**84,320**	**31,299**

Labour: + 20%	**8,551**	**10,543**	**18,204**	**16,864**	**6,260**
Transport: + 5%	**2,138**	**2,636**	**4,551**	**4,216**	**1,565**
TOTAL	**53,446**	**65,894**	**113,773**	**105,400**	**39,124**

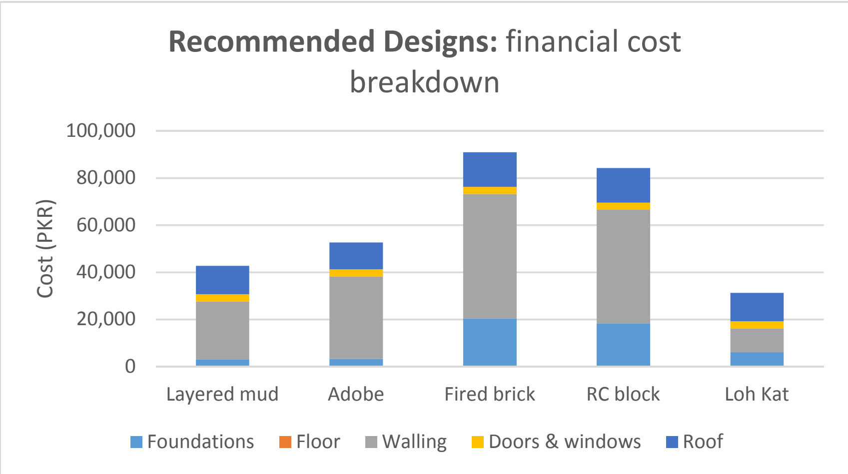


Figure XX. Financial cost breakdown by material type

CO2 (kg)	Shelter wall type				
Element	Layered mud	Adobe	Fired brick	RC block	Loh Kat
Foundations	399	401	2,302	1,231	33
Walling	1,616	3,822	5,167	2,888	448
Doors & windows	0	0	0	0	0
Roof	363	432	477	477	363
TOTAL	**2,377**	**4,655**	**7,946**	**4,596**	**843**

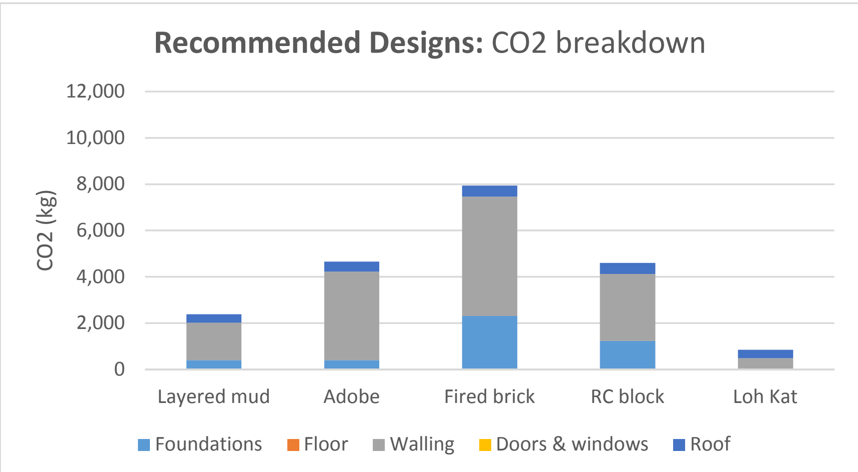


Figure XX. Carbon cost breakdown by material type

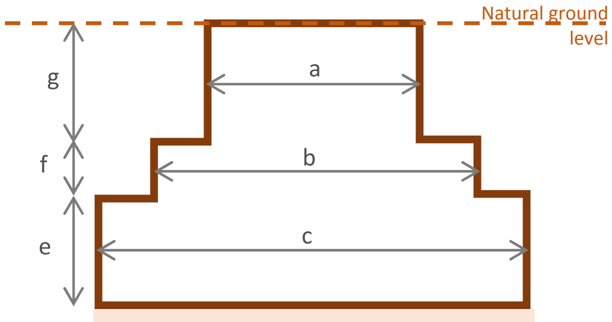
FOUNDATIONS

Select and complete for 1 of the 3 following foundation shape options:

1. Compressed soil (with/ without cement or lime stabilisation)

Section Inputs:

Notes:



a =	0.5	m
b =	0.5	m
c =	0.5	m
e =	0.75	m
f =	0	m
g =	0	m

total volume = 0.375 m^3 /m length

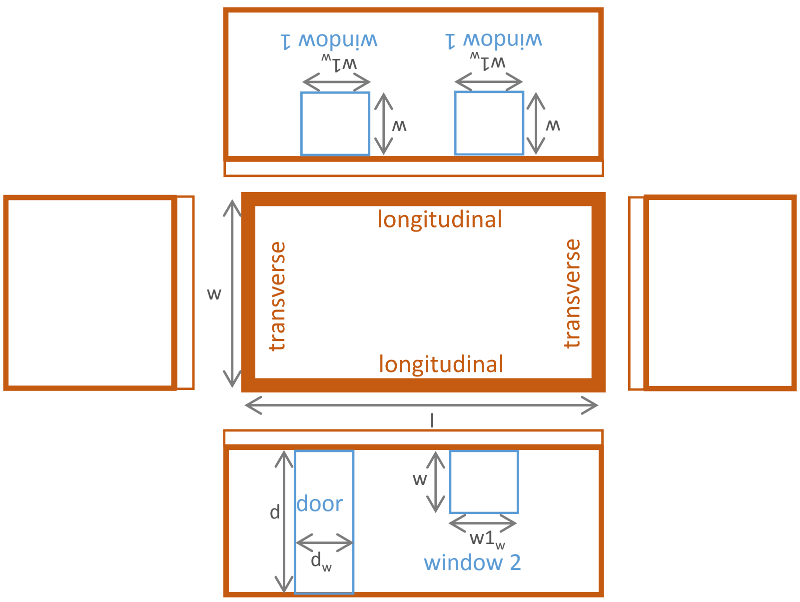
Section Outputs:

Material	Quantity /m wall length				Wall length		Cost	
Fired bricks + cement mortar	0.375	m3	801	kg	19.08	m	25,975	PKR
Adobe blocks + lime	0.375	m3	645	kg	19.08	m	3,222	PKR
Adobe blocks + cement	0.375	m3	702	kg	19.08	m	11,376	PKR
Layered mud + lime	0.375	m3	645	kg	19.08	m	3,016	PKR
Layered mud + cement	0.375	m3	702	kg	19.08	m	11,230	PKR
Hollow concrete block + cement mo	0.375	m3	596	kg	19.08	m	23,252	PKR
Solid concrete block + cement morta	0.375	m4	907	kg	19.08	m	29,962	PKR

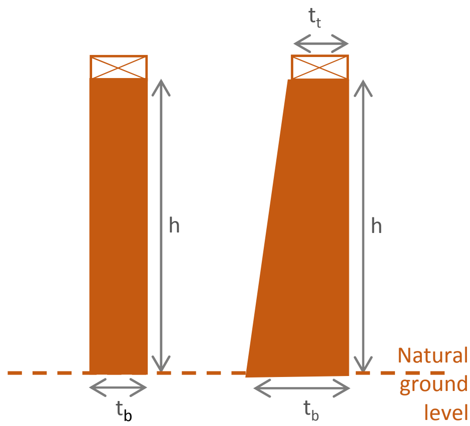
Figure XX. Illustrative example of the foundation parameters included in the cost estimating model

ADOBE WALLS

Plan and Elevation key:



Section key:



Assumptions:

Change in wall thickness is linear constant (so thickness can be taken as an average of top and bottom)
All windows are in upper wall material, there minimum lower wall height must be 1m even if upper and lower wall materials are the same.

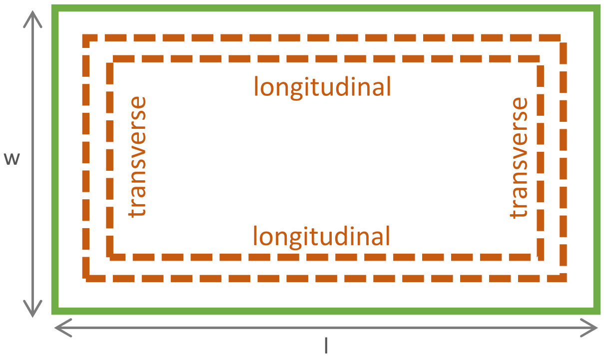
Input:

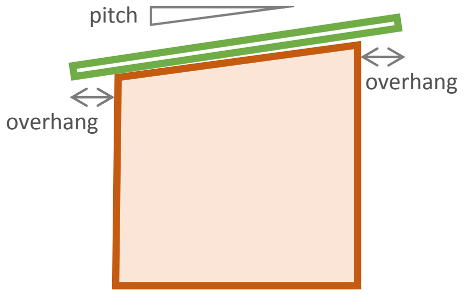
Openings:			*Notes:*
door width, d_w =	0.8	m	*max: 0.8m*
door height, d_h =	2.3	m	
door area =	1.84	m^2	
window 1 height, $w1_h$ =	0.75	m	
window 1 width, $w1_w$ =	0.5	m	*0.5m max*
window 1 area =	0.375	m^2	
window 2 height, $w2_h$ =	0.75	m	
window 2 width, $w2_w$ =	0.5	m	*0.5m max*
window 2 area =	0.375	m^2	

Longitudinal (long) walls:			*Notes:*
wall length (external) =	6.4	m	*6.4m max*
wall length (CL-CL), l =	6.4		
number of doors =	1		
# of window type 1 =	2		
# of window type 2 =	1		
Transverse (short) walls:			
length (external) =	3.9	m	*3.9m max*
transverse (short) wall length (CL-CL), w =	3.9		

Figure XX. Illustrative example of the wall parameters included in the cost estimating model

ROOF - base information





Overhang measure horizontally from building edge

overhang (to all sides) =	0.9	m	*recommend 0.9m, min. 0.4m*
pitch =	5	deg	*min 5deg*
roof width, w =	4.82	m	
roof length, l =	7.3	m	
roof area =	35.17	m^2	

Notes:

<u>Roof fixings:</u>
(Taken as a lump sum average from agency BOQs)

Cost		CO2	
1500	PKR	0	kg

<u>Roof covering:</u>

plastic sheet thickness =	0.002	m
chicks thickness =	0.002	m

Material	Area		Quantity				Cost		CO2	
Plastic	35.2	m^2	0.07	m^3	62	kg	876	PKR	162	kg
Chicks	35.2	m^2	0.07	m^3	21	kg	1609	PKR	8.4	kg

Figure XX. Illustrative example of the roof parameters included in the cost estimating model

Notes sheet

Print this page before you start the following process. Note down your results on the page.

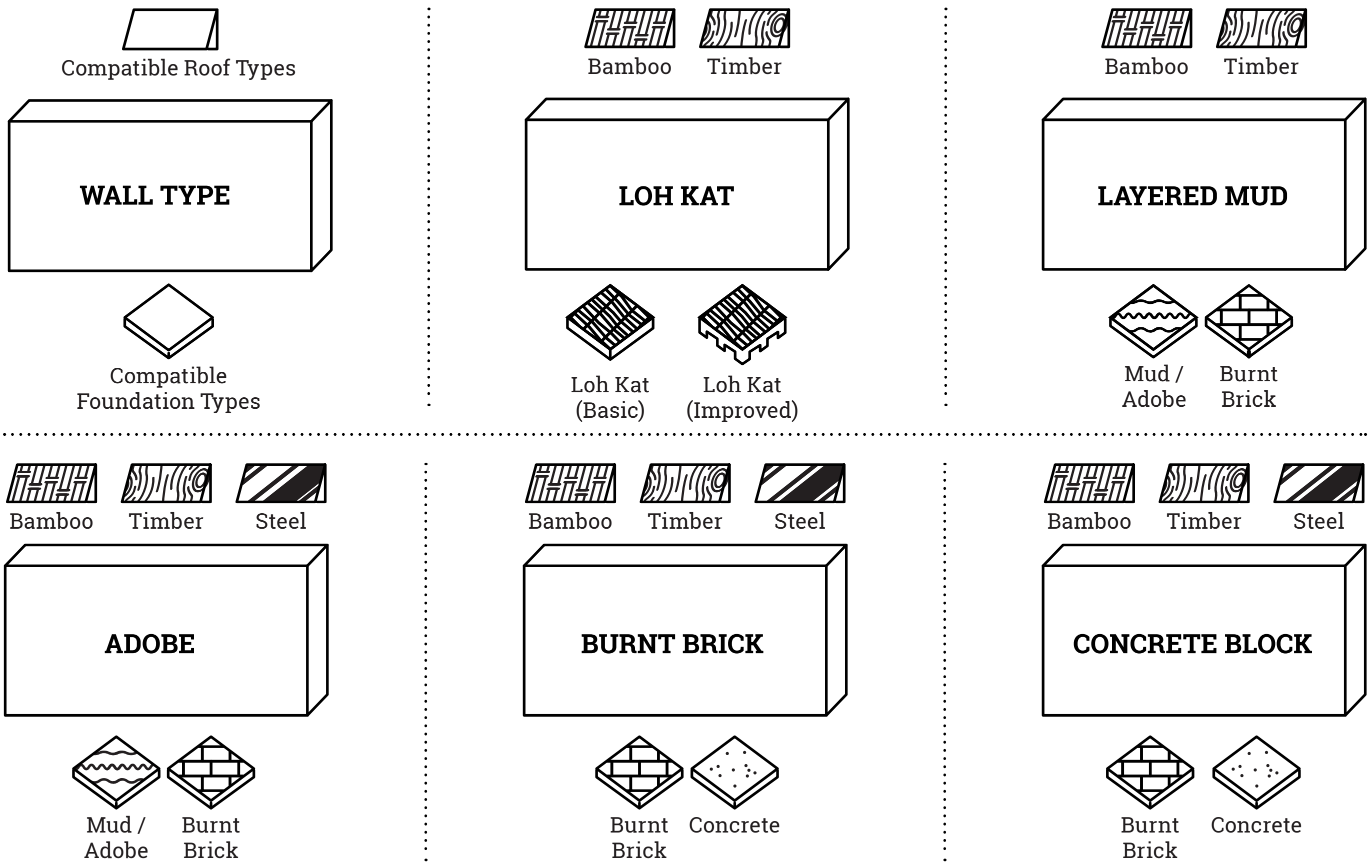
Project name

Budget

Date

Your name

What wall type did you choose?



Notes