01

Design principles

This chapter introduces the fundamental design principles which contribute to the performance of one room shelters in Sindh, Pakistan. The principles are framed by the key performance criteria which are 'Safe and Resilient', 'Acceptable'; and 'Sustainable'. The significance of the performance criteria are explained with examples of how the criteria relate to the designs and key construction details. Within each criterion there are several indicators which have been used to quantitatively and qualitatively inform the design principles and design information. The design information in chapter three is evaluated against these criteria to support the comparison and selection of designs. The most significant principles in this evaluation relate to durability, water resilience, buildability, capital cost and life cycle cost (financial and carbon).

Safe and Resilient

Material Quality

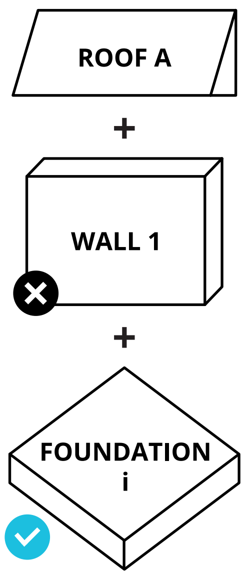


Figure 06. Compatibility

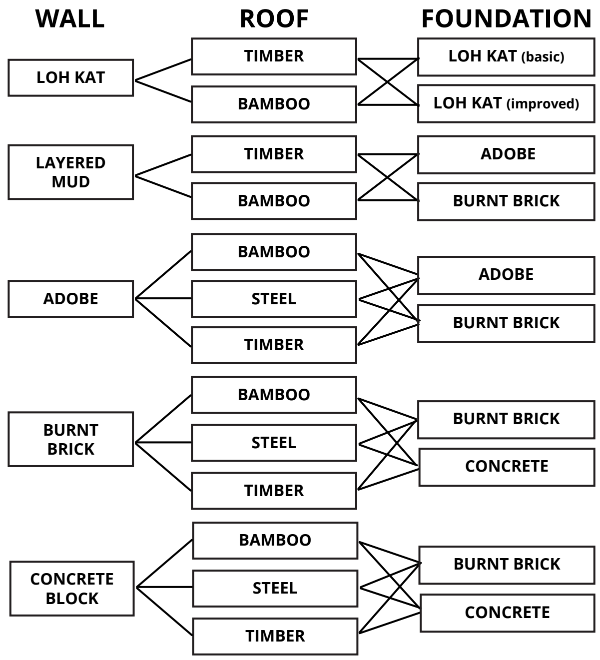


Figure 07. Wall - Roof - Foundation options and their compatibility

Compatibility
Materials and components must be compatible so that individual elements do not undermine the performance of the component or overall design. The surveys reveal several incompatibilities, e.g. mud foundations with burnt brick walls which undermine the overall performance of the design as mud foundations do not have the water resilience to adequately support brick walls[9], thus undermining the flood resistance of the walls themselves. The designs in this guide only use compatible materials within and across components of walls, roof and foundations. The compatibility tree indicates which components can be used together and which should not (see Figure 07).

Durability
Durability influences the overall life span of the shelter and maximises the benefit of the initial capital investment. Roofing was the main durability concern identified in the surveys, with 28% of shelters exhibiting some form of damage to the roof structure. The most common problem was insect attack of timber and bamboo elements which affected 21% of shelters[10]. In particular, the common treatments for bamboo are inadequate and may result in a life span of less than one year[11]. Specifications for material treatment to improve durability are included in chapter four.

Similarly, construction detailing can greatly improve durability, e.g. bamboo and timber should not be cast directly into the ground. The designs in this guide include guidance on appropriate construction detailing.

[9] See Research Report section 6.1

[10] See Research Report section 6.1

[11] Kaminski, S. , Lawrence, A. , Trujillo, D. and King, C. (2016) Structural use of bamboo. Part 2: Durability and preservation. The Structural Engineer, volume 94 (10): 38-43

[12] See Research Report section 6.1

KEY RECOMMENDATIONS: MATERIAL QUALITY

1. Materials and design components (i.e. walls, roofs, foundations) must be compatible (see Figure 07).
2. Materials must be adequately specified, treated to ensure full potential design life, carefully detailed, and strength tested on site to ensure performance (see specifications in chapter four).
3. Soil stabilisation is cost effective, environmentally friendly and can be flood and rain resilient, but it requires specialist training.

Figure 08: Example of low strength wall

Figure 08a: Soil testing

Specification and Strength

Materials should be adequately and appropriately specified. Many of the agency design packages received and reviewed by Arup did not include material specifications. Chapter four of this guide includes specifications for the materials used.

Material strength is a pivotal consideration for any structure. However, few of the reviewed agency designs included minimum material strengths[12]. This guide adopts material strength recommendations based on the following building codes: Uganda, Kenya, Mexico and Eurocode. In addition, material testing for a variety of mud components was conducted at NED University and these results inform the overall material strength recommendations in chapters three and four.

This guide acknowledges that on site material testing may not be very practical or accurate, but several simple tests are recommended in chapter three. For agencies involved in larger scale programmes and procurement, it is recommended that quality checks be conducted at source.

Stablisation

Earth construction is soluble in and easily eroded by water unless it is 'stabilised', whereby it is mixed with lime or Portland cement in ratios between 5% and 10%.

Stabilising soil construction improves flood and heavy rain resilience, making it stronger and more durable. Physical testing has shown that a 4ft flood can be resisted without collapse and that the heavy rain of 2011 can be resisted with minimal or no repairs required. Soil construction should be stabilised up to at least the same level as the maximum previous flood (or likely future flood).

Lime is cheaper than Portland cement, whilst Portland cement is easier to use as it requires less testing. Both lime and Portland cement stabilised soil are significantly cheaper and contain less embodied carbon than fired brick and concrete block.

Soil stabilisation is a science with training in soil suitability, mixing, curing and testing all critical to success. For example different soils are suited to either lime or Portland cement stabilisation and in order to understand whether the stabilisation process has been effective testing is essential, with the best way to do this is to simply place a stabilised soil block in a bucket of water.

Safe and Resilient

Water Resilience

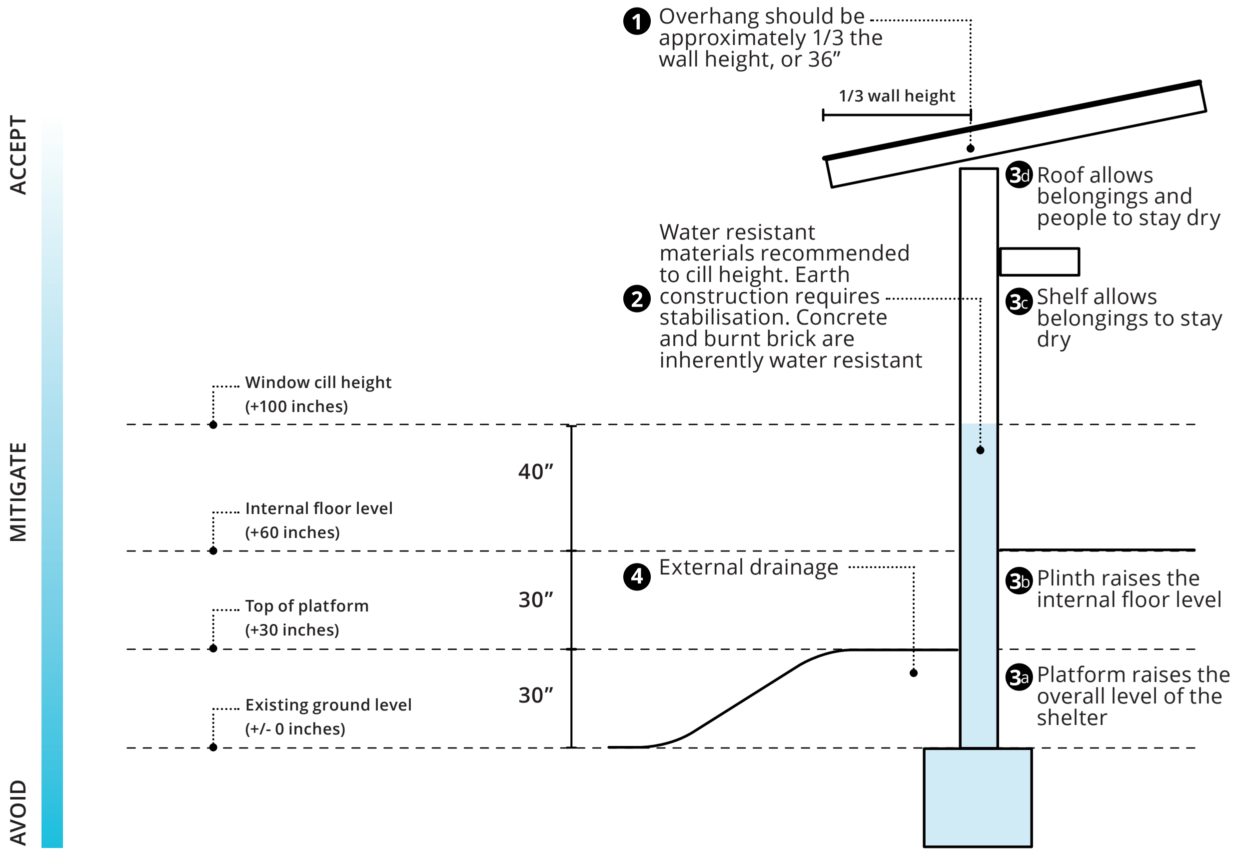


Figure 09. Water resilience for load bearing construction (left) and loh kat construction (right)

Water resilience and flood resistant design are intended to improve the long term performance and ongoing functionality of shelters in response to rainfall and flooding (immersion).

The approach to flood protection ranges from ‘avoid’ to ‘mitigate’ to ‘accept’. Avoid is the preferred approach as it removes risk by appropriately siting the shelter away from a flood zone . This approach is based on a probabilistic hazard assessment which does not exist for flooding in southern Pakistan. Moreover, this guide does not address site selection so flooding cannot be avoided. ‘Mitigate’ attempts to address flood protection by designing in features which can reduce or alleviate the impact of flooding. ‘Accept’ simply acknowledges that flooding will occur, poses a high risk to the shelter and may destroy it.

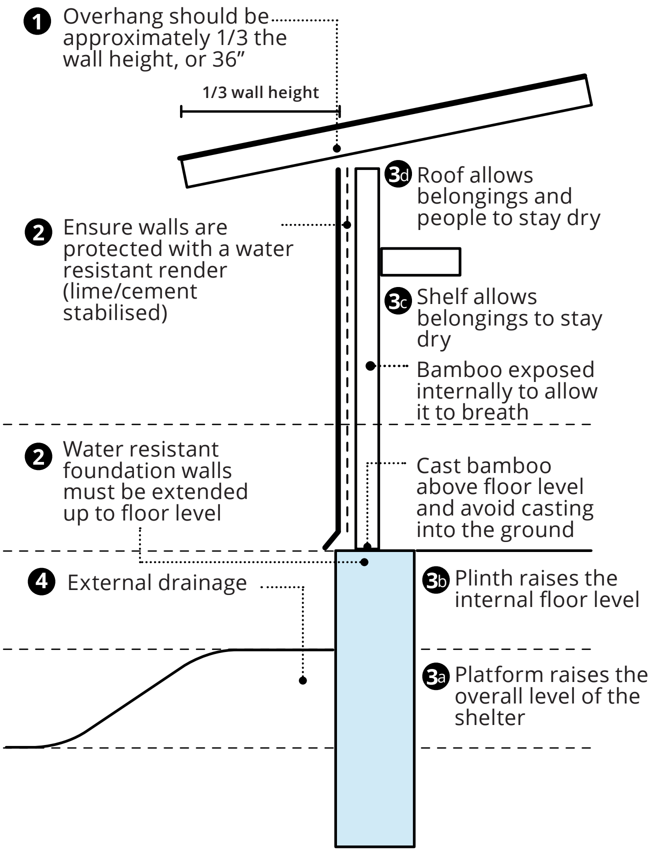
This guide adopts an approach between ‘mitigate’ and ‘accept’. In the absence of a probabilistic hazard assessment, a key consideration is to understand the level of previous floods in the area. If extreme flooding (e.g. 10’ above ground level) is common, the guide recommends ‘avoid’ whereby the shelter should not be built, or ‘accept’ whereby an extremely low cost shelter could be built but will most likely be destroyed in the next serious flood.

In the absence of extreme flooding, the guide recommends a series of designs which can mitigate flood impact and the user can navigate the design decision tool to identify the most appropriate shelter design.

The principles and key features of flood resilient design recommended by this guide adopt the ‘hats and boots’ approach which provides roof overhang protection and enhanced protection of the lower walls and

KEY RECOMMENDATIONS: WATER RESILIENCE

1. Roof overhang should be approximately 36" or one third the height of the walls
2. Water resistant materials used for foundations and walls to a height which corresponds to the future flooding level. Earth construction requires stabilisation. Concrete and burnt brick are inherently water resistant.
3. Raise the internal flood level to provide a usage space for storing belongings in the event of a flood. A platform provides an external dry area.
4. Surrounding ground level is sloped away from the shelter for drainage.



1 Roof Overhang: Rain
36" overhang required in all designs to protect the roof structure, roof to wall connections, and the upper wall from rainfall

2 Water Resistant Walls: Rain & Flood
Walls built using water resistant materials required in all designs to withstand extended periods of immersion. Each wall typology achieves this in different ways

3 Plinth & Platform: Flooding
To maintain the use of the shelter during flood events. Platforms (3a) can be built under the shelter. Plinths (3b) are within the structure and raise the internal floor level. Shelves (3c) and roofs (3d) allow belongs and people to stay dry

4 External Drainage: Rainfall
Area surrounding the shelter is required to slope away from the building to protect from water infiltration and ponding

2 Water Resistant Foundations: Flooding
Foundations built using water resistant materials required in all designs to withstand extended periods of immersion.

foundations. The analysis and physical testing inform recommendations presented in the diagram above.

For maximum protection, in areas where flood levels are likely to be high or unpredictable, the entire wall should be made of water resistant material, to ring beam level.

External drainage should be complimented with consideration for appropriately siting the building, and providing local drainage that accommodates other nearby structures and access routes. This site selection and planning is not included in the scope for this guide.

Raised platforms and plinths will require additional foundation and/or wall build up as the base of the foundations must still be below existing ground level on firm soil. Surveys for this guide indicate that 60 inches would enable the shelter to remain functional in 80% of cases .

Safe and Resilient

Stability and Integrity

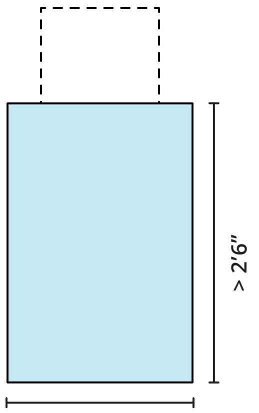


Figure 10. Foundation dimensions

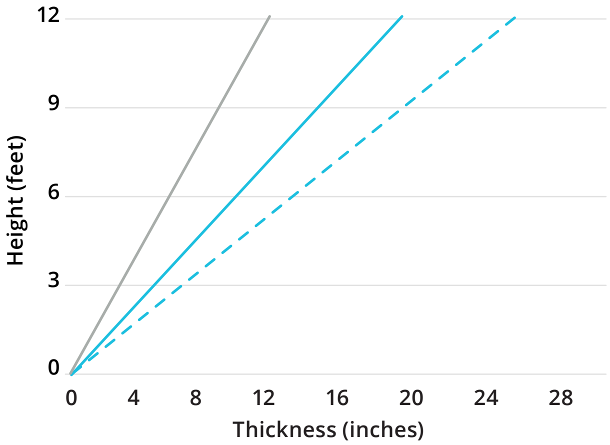


Figure 11. Recommended wall thickness and height for each material based on length not exceeding 19 feet

Foundation Dimensions
All structures require appropriate foundations to transfer loads to and from the ground. The required foundation dimensions fundamentally depend on the nature of the sub soil and the design load. Our review of the agency drawings and as built surveys indicates that existing foundations are generally adequate for hard soil conditions. As such this guide recommends that foundations for hard soils should be at last 2'6" deep for all material types except loh kat which is 1'8" deep. However, these dimensions may not adequate for soft soil types and we recommend that once the minimum foundation depth has been reached, the base of the excavation is checked in order to ensure that hard soil is reached[13]. For clays it should take some effort to press a thumb into the ground, for sand digging with a shovel should be difficult. This may result in considerably deeper foundations.

The surveys revealed that in all cases, except for loh kat, the average foundation width is less than the minimum required. This guide recommends that foundations should be at least 500mm wide and never less than the thickness of the walls (see Figure 10).

Wall Dimensions
The structural limits of a walls length, height and thickness are a result of the material used to build the wall. In general, the longer or higher the wall, the thicker it needs to be. Our surveys and analysis consistently identify walls of inadequate thickness. In particular, concrete block and layered mud walls were overly slender (i.e. too long or tall for the thickness of the block)[14]. There is no uniform guide, or slenderness ratio, for all the wall types recommended in this guide as they vary by material. The slenderness limits for the four masonry-type materials (layered mud, adobe, burnt brick and concrete block) are highlighted in Figure 11. Loh Kat does not have a slenderness ratio as it is designed as a frame. The graphs below indicate the required thickness of walls relative to their height or length depending on the material used. The recommended designs in chapter three satisfy these slenderness rules.

The recommended designs satisfy the most rigorous requirements for maximum window sizes as detailed in the Research Report (Section 6.2). Layered mud is the most constrained material and this window size, which is adequate for daylighting levels, is used throughout the guide.

For Loh Kat walls, spacing of 600mm between vertical poplar or bamboo poles is adequate. At the corners, diagonal cross braces are provided to give stability to the structure.

KEY RECOMMENDATIONS: STABILITY & INTEGRITY

1. Foundations are at least 2'6" deep on firm soil, and at least 1'8" wide but not less than the width of the walls
2. Wall thickness must be individually assessed based on length, height and material
3. All elements are tied together and connected to adjacent elements, especially ring beams and roof to wall connections
4. Roofs must withstand the dead and live design loads, allowing for the roof to be saturated by heavy rain and used as a place of refuge.
5. Roof should maintain a minimum 5 degree pitch

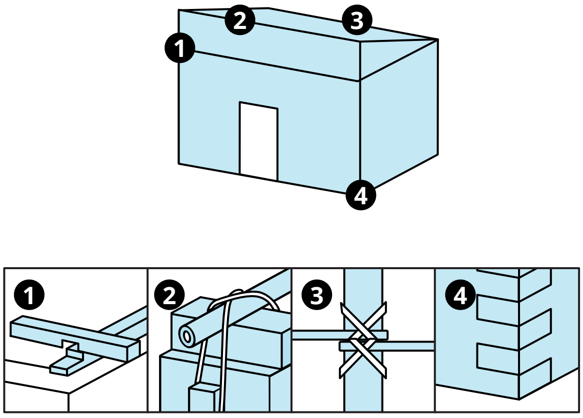


Figure 12. Important connections and tie points

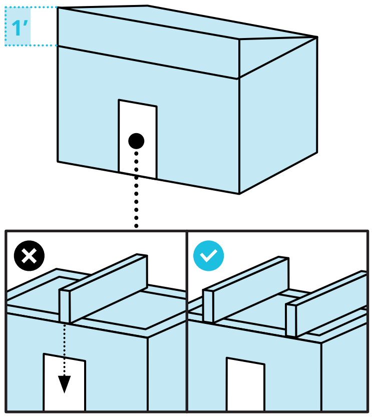


Figure 13. Roof pitch and location of structure

Connections and Tying

All construction elements should be connected or tied to the adjoining construction element in order to ensure adequate structural load transfer, durability and security. Our analysis reveals that in existing shelters the wall to roof connection is generally inadequate as 66% of surveyed shelters reported the roof had lifted off in high winds[15]. There are other potential weak connections and ties at the wall and foundation corners, where verandas are attached to the main structure, the absence of ring beams, and the internal connections within ring beams[16]. Note that as a framed construction technique, loh kat has a ring beam embedded in its design and construction. The designs recommended in this guide include the following principles (see Figure 12):

1. Ring beams with internal connections included by default in all designs.
2. Demountable wall to roof connections to resist wind loads but allow the roof to be relocated.
3. All roof and wall members are internally tied.
4. Brick bonds which connect between wall leaves and courses.

Roof Capacity

Roofs should be designed and built to accommodate the inherent dead load in dry and wet conditions, and any potential live loads (e.g. people accessing the roof). This guide recommends a design dead load of 2.5 kPa and an additional 0.6 kPa to accommodate the live load of people accessing the roof.

A concern identified in the surveys is water logging of roofs which is mitigated in the recommended designs by including a minimum pitch of five degrees in order to prevent water ponding (see Figure 13).

Another concern is the location of wall openings relative to the roof structure . In principle, the primary roof joists should not be placed above openings. Instead they should bear onto solid wall panels in order to ensure maximum bearing capacity (see Figure 13).

[13] See Research Report section 6.2
[14] Ibid
[15] Ibid
[16] Ibid

Safe and Resilient

Buildability, Maintenance and Modification

Figure 14: Example of adobe wall in need of repair

Figure 15: Example of flood damage to loh kat shelter

Communication
Design information must be intelligible to the intended audience. A strong correlation exists mistakes, problems and defects in the shelters surveyed and the information communicated in the design packages. Our review indicates only 10% of agency design packages are considered 'complete'. The missing information primarily relates to the location of windows and doors, spacing for roof purlins or joists, not providing a thickness for mud roofs, and not showing connections between members[17]. All design packages should fully communicate the information required for construction. The designs included in this guide are considered to include all relevant information for design decisions but would need additional information in order to produce a complete construction design package.

Building techniques
Designs must be buildable within the context for which they are intended. Using construction defects as a proxy for build ability, our surveys indicate that loh kat is a challenging building technique as 20% of shelters exhibited defects in the form of gaps in the walls[18]. However, these defects may not be the result of build ability. The ORS evaluation indicates that increased or improved training in construction should be more practical and would potentially improve build ability[19]. The designs recommended in this guide are all based on building techniques commonly found in southern Pakistan whcih should enable them to be built within the existing context.

Tools
The availability and ability to use the required tools is essential for the successful implementation of any design. The tools required to build and maintain the shelters envisaged in this guide are widely available. Surveys recorded that 74% of shelters can be repaired or modified with locally available tools and in generally, the availability of tools was not cited as a limiting factor[20]. This guide uses construction techniques for which tools are widely available in southern Pakistan. However, work by the Heritage Foundation, the results of the ORS evaluation and our own surveys indicate that lime processing is a challenge for individual families and is better suited to a group of builders or a collection of households[21].

Skills and Training
Training is generally required and should be specific to the required construction techniques. The surveys revealed a correlation between low levels of training in loh kat (43%) and high rates of construction defects[22]. While this may not be a causal effect, there is obvious room for improvement. The vast majority of training was well received. However, training for maintenance and repair was generally not conducted[23] and this is recommended as part of this guide in order to extend the life span of shelters and maximise the investment made. There is no evidence that training programmes have resulted in improved livelihoods for residents[24] and therefore, this rationale is not included in this guide.

KEY RECOMMENDATIONS:
BUILDABILITY, MAINTENANCE AND MODIFICATION

1. Ensure the construction documents include all information required to effectively communicate the design intent (see checklist in Research Report)
2. Ensure the building techniques and tools are appropriate, available, and their use is understood
3. Promote the ongoing maintenance and repair of shelters which should include training
4. Allow for the inevitable extension of the shelter which will most likely be a veranda

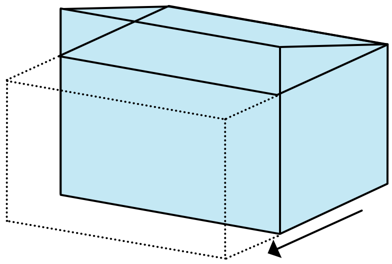


Figure 16. Future expansion

Maintenance and repair

Maintenance and repair are essential for the ongoing functionality of a building and can greatly expand the building life span and therefore the impact of the capital investment. According to our surveys, repairs are generally considered to be difficult with the availability of local materials cited as the most challenging aspect of ongoing maintenance and repairs. Walls and roofs are the most common elements which require repair. The main difference is frequency of repair with concrete block, burnt brick and steel roof shelters requiring half the frequency of repairs compared to adobe/mud brick, layered mud or loh kat. However, burnt brick and concrete block are more likely to require skilled labour to maintain[25].

The consideration of frequency versus complexity of repair is factored into the decision making tool in chapter two. While the relative cost of these repairs is addressed in the section below on sustainability where the capital costs are compared against the life cycle cost.

Modifications

Shelters must be modifiable and will be modified anyway so this should be designed in from the outset as much as possible. The surveys indicate that very few shelters have been modified to date but may well be in the future. The most common modification is the addition of a veranda. Furthermore, it was reported that many residents would like to add a veranda in the future. The safe addition of a veranda should be factored into the design of all shelters. This guide includes recommendations on how this could be achieved by including wooden fixing guides in the entrance wall.

[17] See Research Report section 6.2
[18] See Research Report section 6.4
[19] Shelter Centre, 2014, Evaluation of the ORS Program
[20] See Research Report section 6.4
[21] Shelter Centre, 2014, Evaluation of the ORS Program
[22] See Research Report section 6.4
[23] Shelter Centre, 2014, Evaluation of the ORS Program
[24] Ibid.
[25] See Research Report section 6.4

Acceptable

Comfort

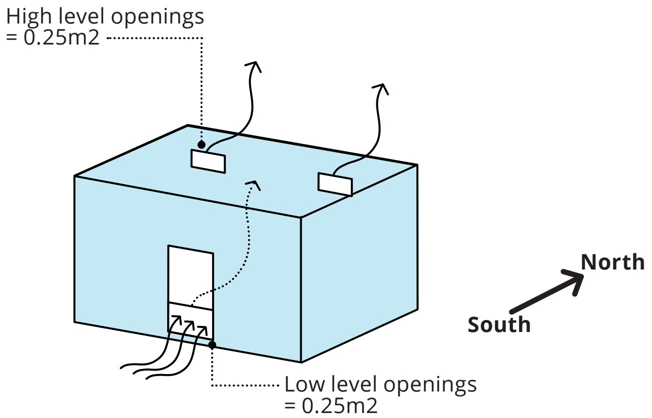


Figure 17. Ventilation

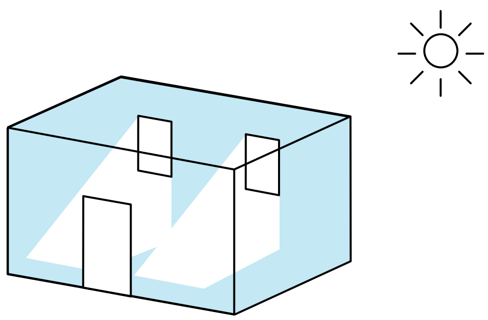


Figure 18. Lighting

Thermal

The internal air temperature of the shelters should be equal to, or below, the shaded external temperature. Our analysis confirmed the survey results which indicate that wall typologies, and window sizes have no significant impact on thermal comfort. Internal air temperatures are generally comparable with shaded exterior temperatures as a result of doors being open and the small size of these shelters[26].

Our analysis indicates that thermal comfort is driven by air flow (ventilation) which could be improved by the provision of two ventilation openings on opposing walls of the shelter. For optimum cross ventilation performance, these openings should have a combined area of least 2% of the floor area, be one high and one low on the vertical plane of the wall, and be located on the north-south walls of the shelter (see Figure 17). Additional thermal gains can be achieved with thicker walls and roofs, however the impact of this is small.

Lighting

Internal lighting should be adequate for normal daily functions, e.g. eating. The existing lighting conditions were not reported in the surveys nor identified in our analysis as being below adequate levels[27]. Therefore, lighting is not considered a significant driver of any design modifications.

However, several recommendations are incorporated into the designs within this guide (see Figure 18):

- One window (approx. 3' x 3') provides adequate natural lighting 70% of the time. Two windows of similar size provide adequate lighting 100% of the time.
- A light coloured internal paint can improve daylighting by 30%.
- Openings should be inherently private and secure by design for efficient use and not simply blocked up as was noted in numerous surveys.
- Jali screens or other similar 'built in' windows only reduce daylighting by 5-15% while still being secure.

KEY RECOMMENDATIONS: COMFORT & SPACE

1. Orientate the long walls of the shelter on an east-west axis
2. Low level ventilation openings of 0.25sqm (these can be out into the door)
3. Minimum of two secure windows (approx 3' x 3' each) on the wall opposite the door. High level ventilation openings, of 0.25sqm, are required (these can be placed above the window)
4. Floor area of 21m2 based on average family size (3.5 sqm per person)
5. Rectangular floor plans with no internal partitions

Space

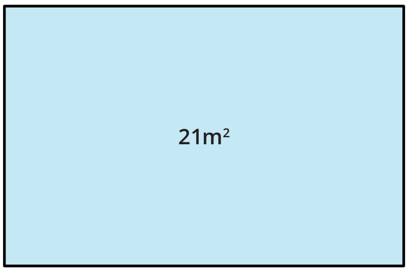


Figure 19. Minimum floor plan for a household of six people

Size

Shelters must meet minimum floor space requirements for residents. These standards are defined by the Sphere Handbook as 3.5 sqm per person[28]. Only 48% of surveyed shelters meet or exceed the sphere standards. 24% of people stated they could not use the shelter as they like and the primary reason for this was lack of space[29]. This guide simply adopts the sphere standards and recommends a minimum area of 3.5m^2 per person. Based on an average occupancy of six people, this guide uses a floor area of 21m^2 as a baseline for design and calculations (see Figure 19).

Layout and Flexibility

While the shelters are small, their layout should accommodate and respond to cultural use. The primary functions attributed to the shelters are sitting, sleeping and storage. In a few cases, they are also used for worship, family gatherings and sewing/handicrafts. In terms of internal organisation or flexibility, there was considerable debate about one or two room shelters in the early stages of the response in 2010[30]. From our surveys, the existing one room shelters appear to adequately support their desired use as the vast majority of respondents did not identify any other activities for which they would like to use their shelters[31].

In terms of layout, the vast majority of existing shelters are rectilinear. While circular plan shelters do exist, there appear to be very few of them. In our survey, only one out of 800 shelters were circular in plan[32]. We note that the Heritage Foundation have discontinued circular plan shelters[33].

Thus, this guide recommends rectilinear shelters with no internal partitions which should continue to adequately serve the requirements of residents.

[26] See Research Report section 7.1
[27] Ibid.
[28] Sphere Project, 2011, The Sphere Handbook
[29] See Research Report section 7.2
[30] Shelter Centre, 2014, Evaluation of the ORS Program
[31] See Research Report section 7.2
[32] Ibid
[33] Heritage Foundation, 2011, Build back safer with vernacular methodologies: DRR-driven post-flood rehabilitation in Sindh

Acceptable

Protection

Insecure and exposed | Insecure but private | Secure but exposed | Secure and private

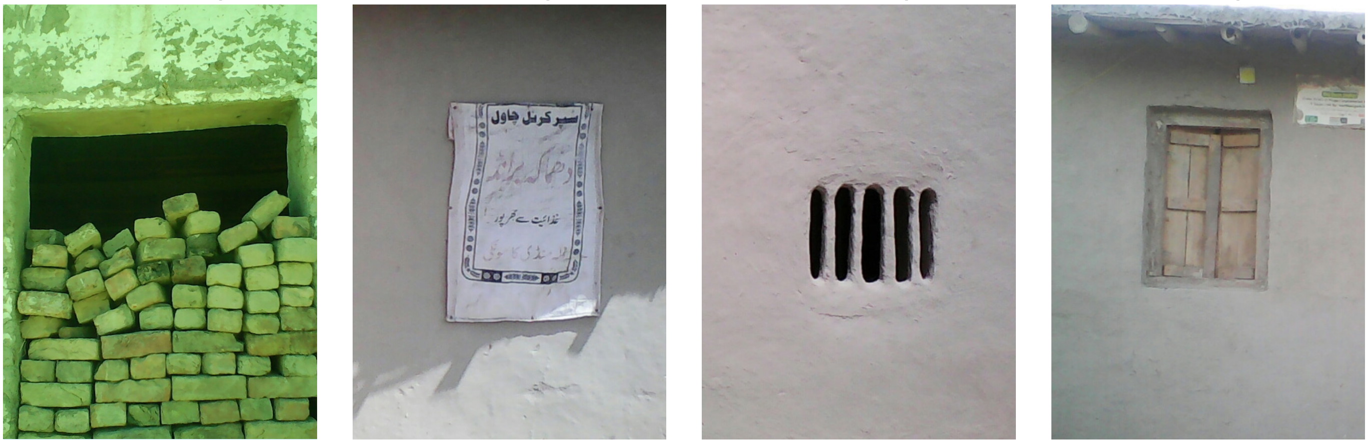


Figure 20. Window conditions vary from insecure and exposed to secure and private

Security
Shelters should provide adequate security for personal protection and the safe storage of valuables. Overall, survey respondents (both male and female) felt secure in their shelters. The lack of doors and windows were cited as the primary reasons for not feeling secure[34]. Therefore, this guide recommends that all shelters should include windows and doors. The fragility of loh kat walls and certain roof types (plastic, chicks, mud) were secondary reasons for perceived insecurity. It should be noted that burnt brick performed significantly better than all other construction typologies in terms of perceived security[35]. There is no technical solution to perceived security concerns and this guide does not attempt to change people's perceptions of security. Therefore, security is factored into the key questions of the design decision tool in order to align security concerns with other (non loh kat) construction techniques.

[52]See Research Report on internal fires
[53]British Building Regs Part J
[54]See Heritage Foundation on external stoves
[55]See Research Report on fire risk
[56]See Research Report on vector control

Privacy
Shelters should provide adequate privacy for normal daily life to be conducted as desired. In general, the overwhelming majority of survey respondents felt their shelter was private. However, there is a notable difference between male (75%) and female (63%) perceptions of privacy. The primary reason for lack of privacy was identified as visibility through openings[36]. As with security above, the inclusion of windows and doors would mitigate these concerns. Therefore, this guide recommends the use of lockable doors, and windows which are operable and lockable (e.g. timber shutters) or inherently secure (e.g. jali screens or 'hit and miss' brick work) (see Figure 20).

Internal Air Quality
The internal air quality should be similar or better than the external air quality. The primary concern identified in this research relates to 15% of survey respondents who report having an open fire inside the shelter. Curiously, a disproportionate number of these respondents live in loh kat shelters which may reveal a correlation to income levels, however, this cannot be ascertained in the data[37]. While an indoor stove could potentially be accommodated by introducing a 200mm diameter flue with permanent vent[38], this is a considerable additional cost and material that may not be available for a very limit number of cases. It is noted that the Heritage Foundation are promoting an external stove system rather than an internal one[39]. Therefore, this guide recommends that cooking should happen outdoors and this will ensure internal air quality stays within acceptable parameters.

KEY RECOMMENDATIONS: PROTECTION, HEALTH & SAFETY

1. Ensure doors are secure and lockable; and windows are operable and lockable (e.g. timber shutters) or inherently secure (e.g. 'hit and miss' brickwork)
2. Avoid indoor fires in order to reduce fire risk maintain air quality
3. Include insect mesh on doors, windows and any clerestory gaps

Health and Safety

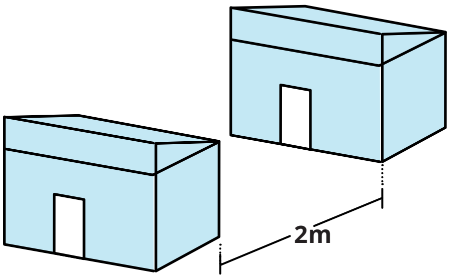


Figure 21. Distance between shelters for fire safety

Fire Hazards
The shelters should a limited fire risk to inhabitants or neighbours. The use of indoor fires are an obvious concern and, as noted above, this guide recommends that fires should only be outdoors. Assuming that open flame sources are only found outdoors, the recommended designs exhibit limited fire risk. Most of the materials are non-combustible, with the exception of timber and bamboo roof materials, and loh kat which may pose a risk – particularly if the earth render has degraded and the wooden sub structure is exposed. The spread of fire between units is also understood to be low given low density of settlement and distance between shelters. In order to maintain this safety factor, this guide recommends shelters should not be built in close proximity of each other to reduce fire risk.

Vector Control
Shelters should protect inhabitants from vector borne risk by reducing exposure to, principally mosquitoes. This guide does not address water borne disease as that is outside the control of shelter design. However, unfortunately the data are inconclusive as to whether existing shelters increase, decrease or have no effect on malaria or dengue fever[40]. Geographical mapping of vector risk areas would need to be correlated with shelter and any clear-story gaps at ceiling level would help to decrease exposure. This approach is preferred to bed nets given the number of occupants and shelter size. However, insect mesh would need to be diligently maintained in order to be effective. A detailed design option for this approach is included in the design information presented in this guide.

Sustainable

Cost

BUDGET RANGE (USD)	FOUNDATION	WALL	ROOF
<$400	Loh kat (basic), Adobe	Loh kat, Layered mud, Adobe	Bamboo, Timber, Steel
$400 - 700	Loh kat (improved), Burnt brick	Loh kat, Layered mud, Adobe	Bamboo, Timber, Steel
$700 - 1,000	Burnt brick, Concrete	Burnt brick, Concrete block	Bamboo, Timber, Steel

Figure 22. Capital construction costs for component and material types

Construction Cost
Shelters should be affordable for government agencies, implementing agencies and households themselves. The significant expansion of coverage achieved by Shelter Cluster was predicated on individual shelters costing approximately US$500[57]. This guide has adopted a similar threshold but acknowledges that several designs exceed this range. Materials are a fairly fixed cost which typically require 70-90% of the construction budget. Construction costs also vary by component, i.e. foundations, walls, and roof types, with average breakdowns of 15% for foundations, 55% for walls and 39% for roofs[58]. Therefore, material choice will largely be informed by cost.

Labour costs may vary and typically range from 10-30% of the construction budget[59]. Unskilled labour could be provided by the household or family and this could reduce costs somewhat. Similarly, if friends or family can provide skilled labour this may also reduce costs. Training is another way to offset construction labour costs and potentially provide livelihood opportunities though the measured impact of training on livelihoods currently underwhelming. However, the costs indicated in this guide assume that all labour is paid.

This guide recommends a hierarchy of material and component types based on cost (see Figure 22).

Life Cycle Cost
The life cycle costs of a shelter should be considered at the design stage and the decision making process should include the individual household or village level considerations. Depending on circumstances, the preference may be for the lowest capital cost shelter with a short life span or a higher cost shelter with a longer life span. Our analysis does not reveal an optimum solution which is the lowest cost shelter with low maintenance costs that is longer lasting[60]. However, regular maintenance can greatly extend the life span of the shelter.

Based on the surveys, our analysis and judgement this guide sets a minimum life expectancy for all designs of 5 years and a preferred life expectancy of 15-30 years which only some of the designs may achieve. Our projections assume that once this life expectancy has been reached, the shelter will need to be completely rebuilt and the capital cost of construction reoccurs.

Operational and maintenance costs are considered in two ways: frequency and unit cost. In general, the more robust materials (e.g. concrete and fired brick) require less frequent maintenance. Whereas, loh kat requires regular maintenance once or twice a year. Repairs in response to specific events (e.g. flooding) are additional to these maintenance requirements. However, due to the high cost of concrete, fired brick and associated skilled labour the cost of maintenance for concrete and fired brick is disproportionately high relative to the cost of maintaining loh kat[61].

KEY RECOMMENDATIONS: COST

1. Select the material and component types based on the available budget which ranges from approximately $400 - $1,000 (USD)
2. Consider the life cycle costs during the design decision process as some materials (e.g. burnt brick) have high capital but relatively consistent life cycle costs. Whereas other materials (e.g. loh kat) may have low capital but higher life cycle costs

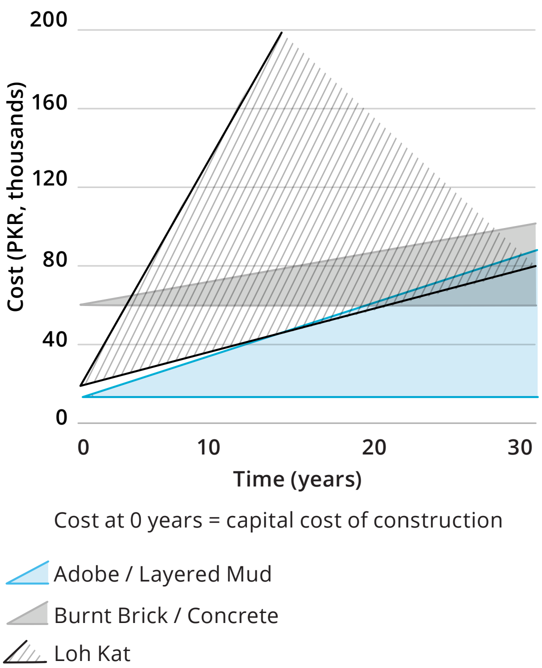


Figure 23. Life cycle costs for walls and foundations

Figure 24. Life cycle cost for roof structure

The comparative life cycle cost ranges are graphed above and more information is available in chapter four. Foundations and walls have considerably more influence on life cycle costs relative to roofs.

This guide does not make a specific recommendation on which design to choose from a life cycle cost perspective as that depends on user preference. Instead we present a summary of the data to inform the decision making process:

1. Lowest life cycle cost could be layered mud and adobe if both are well built, maintained and avoid excessive flooding. However, layered mud could prove quite expensive if there is an ongoing need to replace walls. Steel is generally the roof type with the lowest life cycle cost.

2. Mid range life cycle cost is for burnt brick or concrete walls and foundations which have relatively high capital costs but comparatively lower maintenance costs over 30 years. Well maintained bamboo or timber roofs could also be mid range.

3. Highest life cycle cost is most likely for loh kat walls and foundations given their comparatively shorter design life, need for frequent repair, and risk of insect attack. Timber and bamboo roofs may also have the highest life cycle cost if they are inadequately maintained or repeatedly attacked by insects.

[57] See Corsellis et al

[58] See Additional Information for cost profiles

[59] See Research Report on labour costs

[60] See Research Report on life cycle costs

[61] See Research Report on maintenance costs

Sustainable

Local Supply Chain

Availability of Materials
The materials required for construction should be locally available. While availability and cost may change, the surveys reported that 70-80% of all materials were "easy to obtain" which indicates that markets are working, supply is responding to demand, and hypothetically that demand may adjust in response to supply. The most challenging materials to procure were concrete blocks, bamboo, steel, window and doors. Procurement is restricted due to distance and the potential need for motorised transport. However, all existing materials are reportedly available within 15km of the site which is considered acceptable[62]. Therefore, this guide does not restrict or omit any of the existing materials from our recommended designs.

Labour Standards
Shelter programming must ensure that human rights are respected, harm to people is avoided and efforts are made to maximise the positive contribution of the project ensuring that human rights are met throughout the supply chain. Our surveys indicate that 91% of homeowners were involved in the entire construction process and people are more inclined to want to be more involved rather than less involved in the future[63]. However, it should be noted that Shelter Centre's evaluation indicates that the process of homeowner involvement reinforced women's traditional role as builders and forced them to work harder rather than dividing the work with men[64]. In terms of child labour which is traditionally associated with burnt brick production, the agencies report strict child labour policies with effective monitoring systems[65]. It was not possible to confirm the effectiveness or enforcement of these policies as part of this research.

The volume of reported injuries on site is comparable to the UK construction sector and within acceptable limits[66]. However, it can be assumed that the number of actual injuries exceeds the number of reported injuries.

[62] See Research Report on local supply chain

[63] See Research Report on household labour invovlement

[64] See Corsellis et al....

[65] See Research Report on what was stated by agencies about labour standards

[66] HSE: hse.gov.uk/statistics/industry/construction

KEY RECOMMENDATIONS:
LOCAL SUPPLY CHAIN & NATURAL RESOURCES

1. Utilise local materials wherever possible
2. Enforce labour policies (e.g. child labour in burnt brick production); consider women's traditional role in construction and how this can be shared (e.g. accommodate harvest season in scheduling); and record injuries on site
3. Pro-actively consider the handling and disposal of toxic materials (e.g. lime)
4. Prioritise renewable materials and those with low life cycle embodied energy (e.g. layered mud and adobe); and research alternative burnt brick production

Natural Resources

In terms of recommendations, this guide suggests:

1. Future implementation should be aware of the harvest season and enable women, in particular, to adjust the time lines of construction to their existing commitments.
2. Child labour policies are probably adequate and every effort should be made to enforce them. However, it must be acknowledged that children may help their families during construction and in this context it may not be possible to monitor all aspects of the supply chain.
3. Injuries should be monitored and recorded to understand what the injuries are, their severity and what caused them. In particular, as power tools or more complex construction methods are adopted, injuries may become more severe.

Recycled / Reused
Materials should be reused or recycled as much as possible in the context of a resource scarce environment. Our surveys indicate that materials are extensively reused and recycled. There were only five instances reported form 800 surveys of materials being unused following construction which indicates that materials are reused/recycled by necessity. In particular, windows and doors are frequently reused[67]. Therefore, it appears unnecessary at this time to make recommendations about the reuse or recycling of materials as it is already being carried out by default. However, there are some concerns about the disposal and handling of certain toxic materials, e.g. diesel, red oxide and lime[68]. It is recommended that these materials should not be used at the household level but only at community level in order to improve the likelihood of adequate storage and handling. Shelter Centre indicate that this is already happening for lime given the efficiencies of scale in the production process[69].

[67]See Research Report on recycled/reused materials
[68]See Research Report on toxic materials
[69]See Corsellis et al
[70]See World Bank
[71]See Research Report on embodied energy

Sustainable

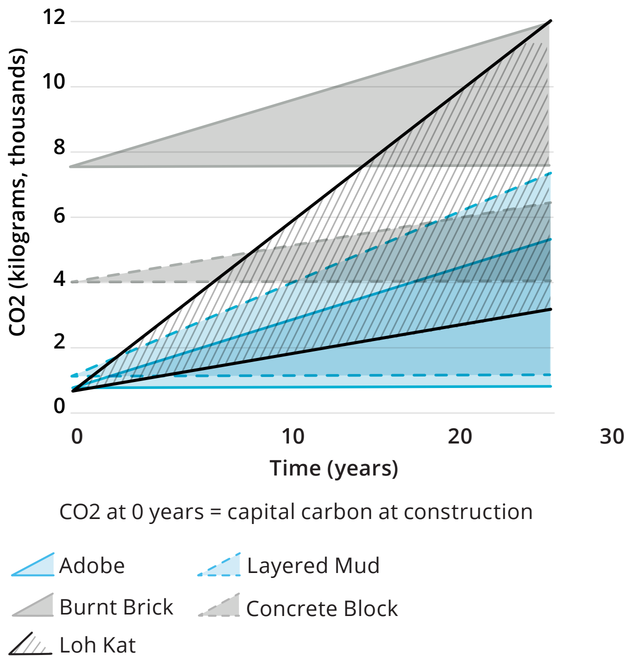


Figure 25. Life cycle embodied energy for walls and foundations

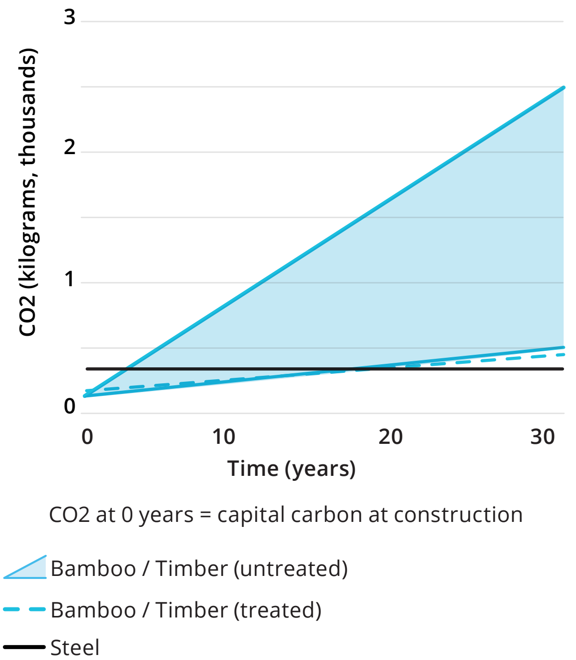


Figure 26. Life cycle embodied energy for roofs

Embodied Energy

The embodied energy and carbon emissions associated with construction must be reduced globally. Though Pakistan is ranked 155th in terms of carbon dioxide emissions per capita[70], an opportunity exists to avoid energy intensive development trajectories. Based on our analysis, the walls of a shelter are the largest contributor to overall carbon dioxide per square metre. The embedded carbon dioxide in initial construction of shelters ranges from 50 – 350 kg/m2 with adobe and potentially layered mud at the low end, and burnt brick or loh kat or layered mud at the high end.[71]

However, the life cycle range for loh kat and layered mud is very broad and this depends on how frequently the walls need to be replaced based on the quality of initial construction and ongoing maintenance. Our calculations do not account for sequestered carbon associated with lime, bamboo and timber which may have an impact life cycle carbon analysis.

The carbon footprint for burnt brick shelters is a concern and can be compared to benchmarks developed by Arup for steel and concrete buildings in the UK. However, given the comparatively longer life span of UK buildings, the Pakistan shelters should be considerably lower than this UK benchmark. This guide recommends that renewable resources (e.g. adobe, mud, bamboo) be prioritised for shelter design and alternative fired brick production be researched in an effort to reduce the carbon footprint for this material.