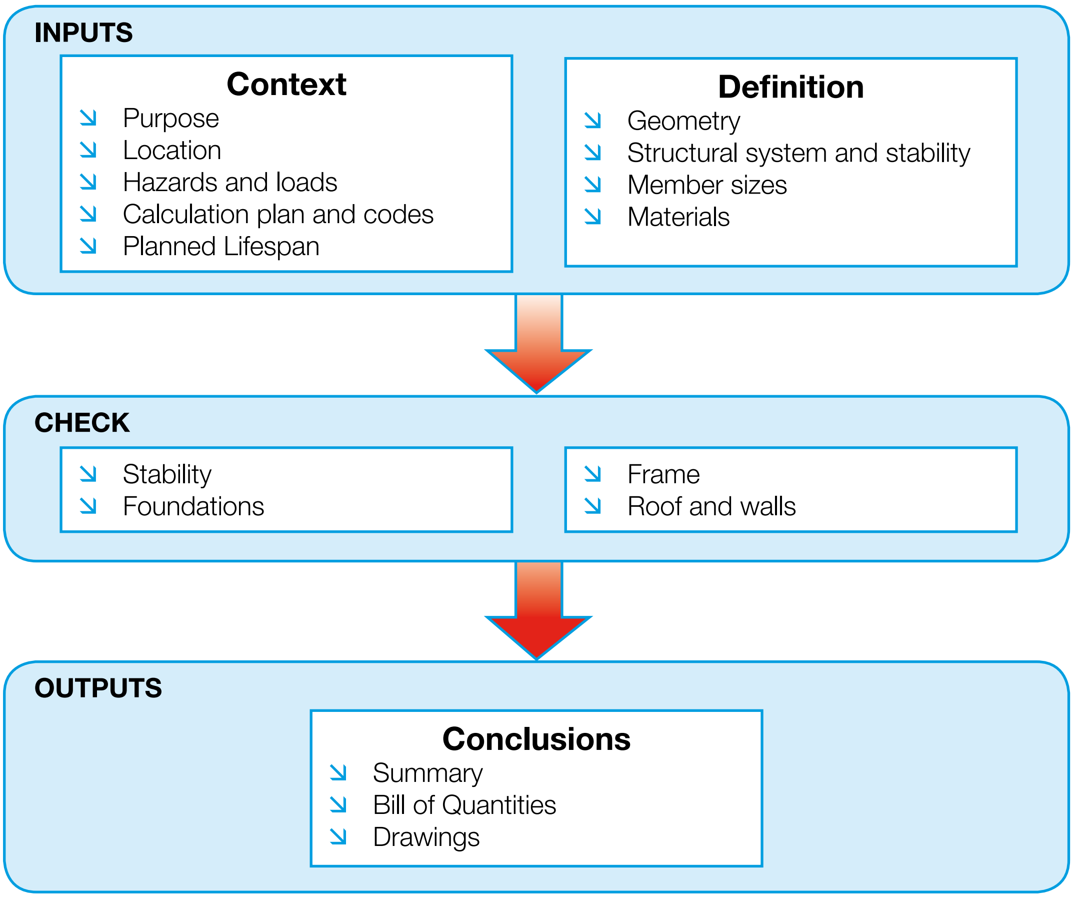
A.4 How the structures were reviewed

A.4.1 Process

This section discusses how the structural aspects of the shelters in Section B of this book were checked. To check the shelters a three stage process was used. This is illustrated below:

- **INPUTS.** Information on the shelter was gathered. This included information on the broader context including the purpose and proposed lifespan of the shelter and where it was built. This determined the hazards and loads it would be exposed to and which building codes and standards are relevant. The shelter was then defined in terms of its geometry, stability system, member sizes and materials. When information was not available, assumptions were made.
- **CHECK.** The performance of the main elements of the structure was checked against relevant codes and standards (A.4.2 Approach to codes and standards).
- **OUTPUTS.** Annotated drawings of the as-built shelter, an associated bill of quantities, a summary of structural performance and recommendations for improvements were produced as final outputs.



Caption: Illustration of the process by which shelters were checked

A.4.2 Approach to codes and standards

Codes used

The 🕮 International Building Code (IBC) 2009 (See Annex I.6) has been used as a reference for the design checks on the shelters. It is globally recognised and provides a good basis for calculating extreme loading cases such as earthquakes or strong winds. Other building codes were referenced when they were available or appropriate.

🕮 See annex I.6 for a more detailed explanation of how building codes were applied

Risk to life or risk of structure being damaged

The performance of each shelter in section B was assessed on whether or not the shelter was safe for habitation.

As an example, a major risk to people in shelters during extreme high wind is from wind-blown debris. For the most part, post disaster structures are not intended to be shelters during such events. Therefore, they are not only rated on the maximum wind velocity during which they will maintain their functionality but also their ability to be repaired and returned to functionality after an event that exceeds that maximum wind velocity.

As a structure may deform significantly under extreme hazard loading without posing a high risk to life, each shelter was also assessed on the risk of it failing or being damaged (A.4.4 Classification of performance).

Because most post disaster shelters are lightweight, the risk that falling parts of the building would severely injure people is reduced. However, if a shelter is damaged, it will often need to be repaired or rebuilt.

Regarding fire safety, simplified and comparative assessments of the flammability of materials were performed. Comments were based on the ability of occupants to escape from these small structures.

Applicability of building codes to post disaster shelters

For the shelter reviews in this book, design criteria have been developed based on the codes and standards discussed above. These criteria take into account the intended lifespans of the shelters.

Building codes are typically developed for permanent structures. They are not directly applicable to post disaster shelters. Therefore, to assess structures against a standard of complete code-compliance is unreasonable. The sections of the codes and standards referenced herein which apply to post disaster structures have been noted and are used as a guideline for assessing the structures. Key assumptions and reasoning for interpreting the standards are stated in the “assumptions” sections for each shelter review (see Section B).

Local codes and standards such as those listed above have been reviewed and utilized. It is understood that the local standards may be more applicable to post disaster structures than the IBC.

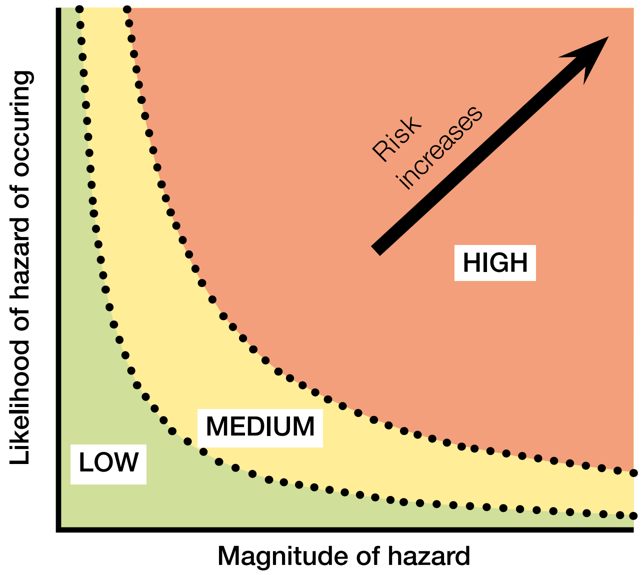
Connections and workmanship

In addition to the overall design, the performance of a shelter is dependent on the quality of workmanship and connections between elements. These aspects are not covered in this book but are important considerations in delivering a post disaster shelter programme.

A.4.3 Classification of hazards

Magnitude, likelihood and risk

For the purposes of this book, the earthquake, wind and flood hazards in each location have been classified as **HIGH**, **MEDIUM** or **LOW**. These simplified categories are based on hazard criteria as applicable to lightweight, low rise buildings, and statistical assumptions about the likelihood of hazard occurring.



Caption: The risk is a combination of the likelihood of the hazard occurring and the magnitude of the hazard. Note that an event with a high likelihood can still be a low risk if the expected magnitude is low

	Hazard risk classification used in Section B for earthquake, wind and flood				
Classification used	**Earthquake**	**Wind (approximate)**		**Flood**	**Fire**
	Seismic Design Category *	Basic Wind Speed ** (km/hr)	Saffir/Simpson Hurricane Category		
LOW	B	< 113	< 1	Low risk	Low risk
MEDIUM	C	113 - 160	1-2	Medium risk	Medium risk
HIGH	D	> 160	3-5	High risk	High risk

* This is based on 📖 ASCE/SEI 7-10, Table 11.6-1 assuming Risk Category I (Table 1.5-1 representing a low risk to human life in the event of failure) and based on the modified PGA.

** The sustained 3 second gust speed at a height of 10m in flat open terrain for a 50 year return period (as defined in the 📖 International Building Code (IBC) 2009, Section 1609.

A.4.4 Classification of performance

The performance of each shelter has been categorised using a **GREEN**, **AMBER**, or **RED** scheme. This classification is for the risk of the structure failing or being damaged. It is not based on the risk of the structure injuring people if it does fail. (See annex I.7 Building codes and post disaster structures)

Classification used in Section B for the performance of structures	
Classification	Meaning of classification
GREEN	Indicates that the structural system fully meets the factors of safety and all other requirements of the International Building Code and local standards (if they exist) for the reduced design loads.
AMBER	Indicates that the structural system does not fully meet the requirement of the International Building Code, or local standards if they exist. However, the reduced design loads will not cause failure of individual members of the structural system or its overall collapse.
RED	Indicates that the reduced design loads will either cause complete failure of individual members or cause overall collapse of the structural system.

A.4.5 Performance analysis summaries

Each shelter review in Section B has a table titled 'performance analysis'. This table provides an overall summary of the robustness of the shelter. The table assesses the performance (A.4.4 Classification of Performance) of the shelter with respect to the hazards (A.4.3 Classification of Hazards) at the given location.

See A.4.4 Classification of Performance

See A.4.3 Classification of Hazards

Example of a Performance analysis	
Hazard	**Performance**
Earthquake LOW	**AMBER**
Wind MEDIUM	**RED**
Flood HIGH	**GREEN**
Fire LOW	**AMBER**

Structure is expected to deflect and be damaged under earthquake loads.

Structure is expected to fail under wind loads.

B.5 Haiti – 2010 – 'T-Shelter'

Summary information

Disaster: Earthquake, January 2010

Materials: Wood framed walls with clissage infill, corrugated bitumen on timber trusses, concrete slab floor.

Material source: Internationally procured

Time to build: 66 man days, but could be built in less than 2 weeks onsite

Anticipated lifespan: 3 – 5 years

Construction team: 10 people plus fabrication team in warehouse

Number built: 1,050

Approximate material cost per shelter: 1,650 CHF materials, 850 CHF (for staffing, supervision and labour)

Shelter Description

This shelter is a rectangular timber framed structure with a gable roof and a covered floor area of approximately 5.4m x 3.7m with a covered porch measuring approximately 1.8m x 3.7m. The roof has wood and corrugated bituminous roofing supported on timber purlins and trusses. The exterior walls are wood framed, and the wall infill is constructed using a traditional technique called clissage, which consists of thin slats of wood woven between the wall framing. The foundation consists of wood posts embedded in concrete piers, and the floor is an elevated concrete slab supported by a short masonry wall between the wood posts. As designed, the shelter has one door and two windows. The shelters were designed to be accessible by persons with reduced mobility and individual modifications were made according to personal needs.

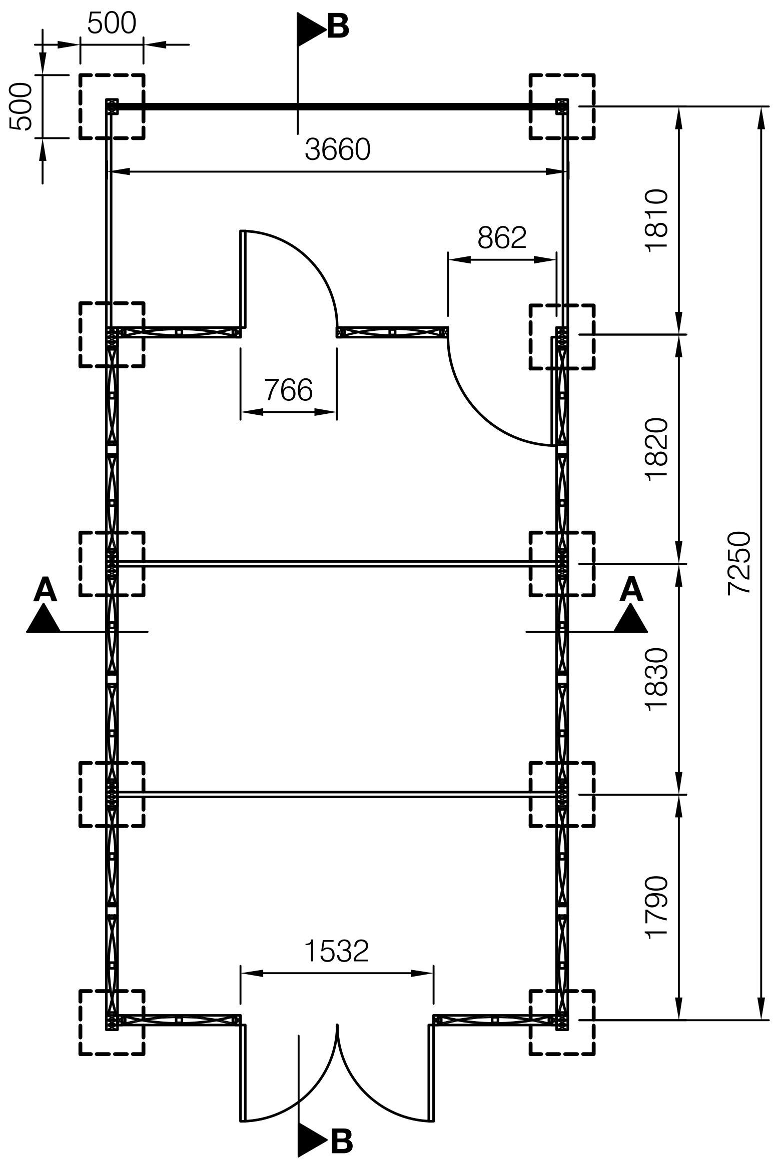
Shelter Performance Summary

The construction of this shelter is based on traditional techniques typical to Haiti, which has a successful historical track record. The clissage walls allow excellent ventilation if they are left uncovered, and they can also be reinforced with mud or mortar to provide a solid wall. This technique allows for the use of local labour, and reduces the size and volume of material required, allowing construction in remote areas.

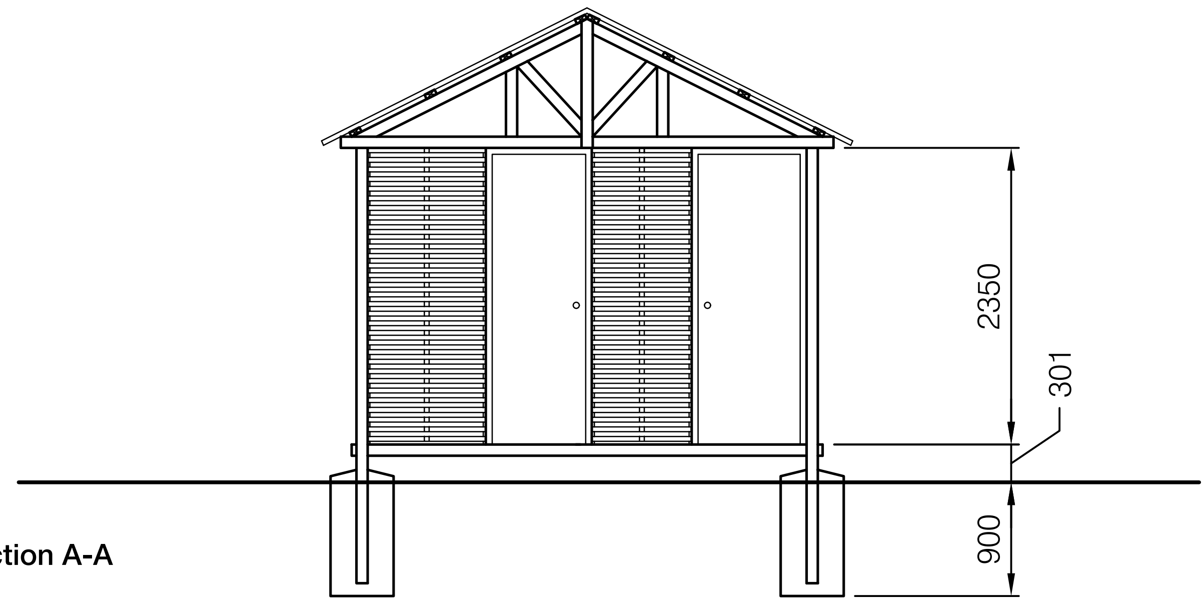
Unfortunately there is only anecdotal evidence for the performance of the framing system, and there is little, if any, engineering data or analysis techniques for this construction type. Therefore, the adequacy of the lateral load resisting system cannot be verified. Filling in the walls will increase the lateral load capacity, but the weight and brittle properties of the wall most likely will not perform well in a severe earthquake or under high winds. Laboratory tests of the wall panels are required to determine their lateral load capacity for future analysis.

The masonry foundation wall raises the floor, providing resistance to flood damage. Using preservative treated wood and/or protective coatings would help prevent deterioration of the frame, increasing the shelter lifetime.

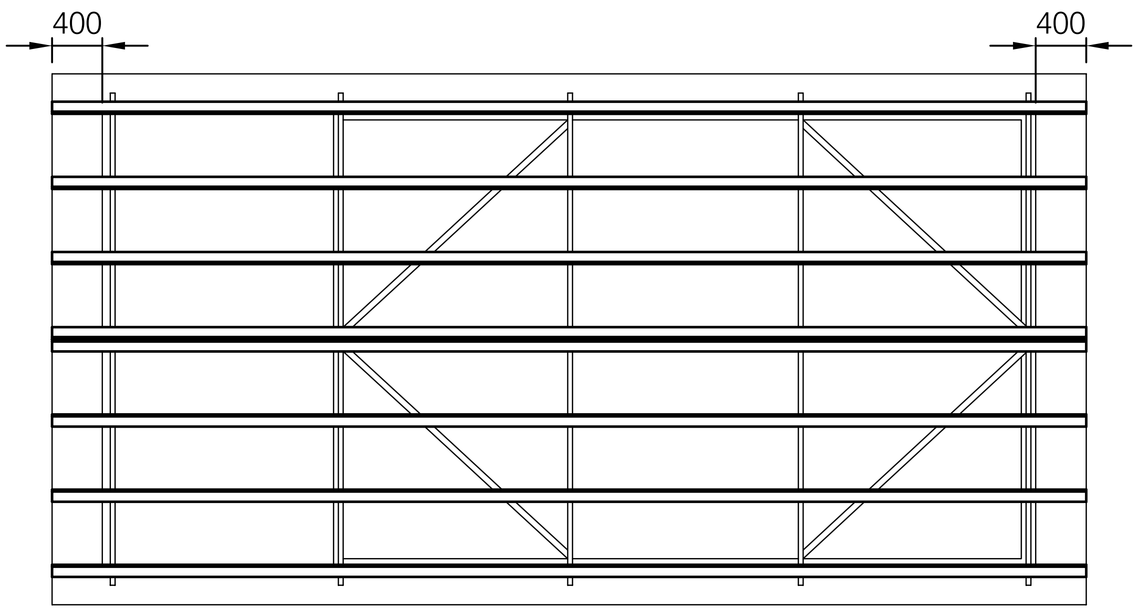
Plans



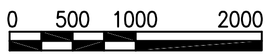
Floor plan

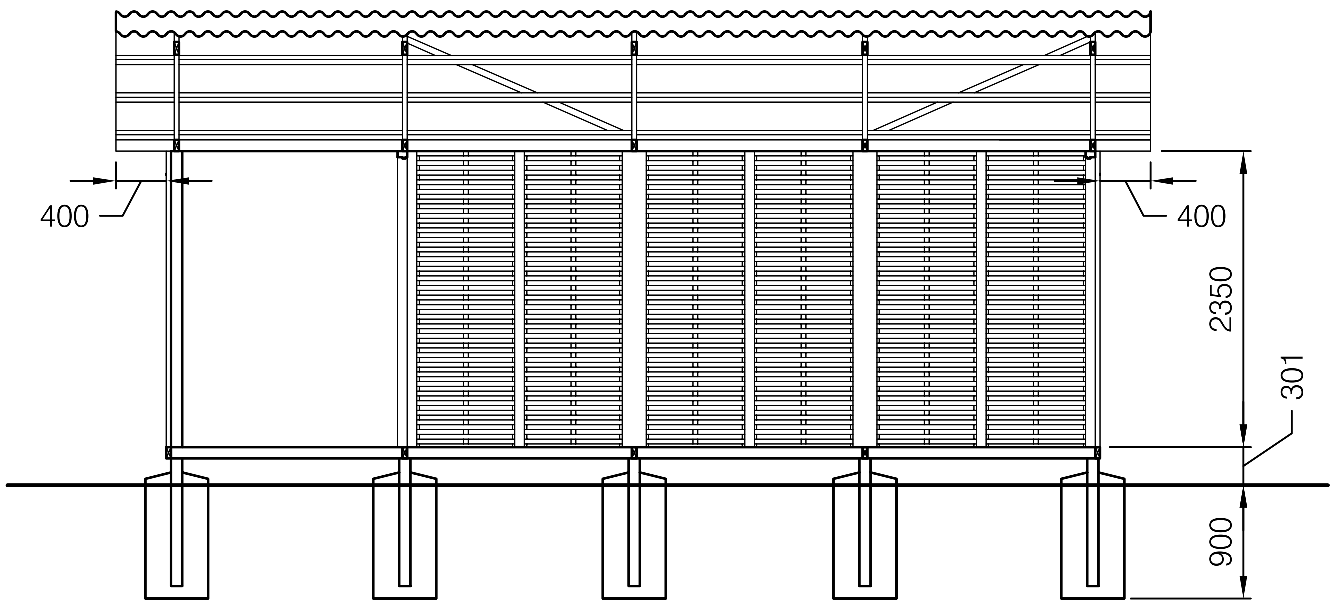


Section A-A



Roof Framing Plan





Section B-B

Durability and lifespan

Because There is limited engineering data available for the clissage technique, It is not certain how well the shelter will perform in large storms or earthquakes.

Given the tropical climate in the summer and the presence of termites, the timber was pressure treated before construction. All nails, fasteners, and hurricane ties were hot dip galvanized.

Performance analysis	
There is a lack of data on the performance characteristics of the clissage walls under lateral loading, it is not possible to determine the performance of the shelter under wind and earthquake with any accuracy. Proper site analysis is necessary prior to construction to determine appropriate finished floor heights to provide any mitigation of flood hazards To fully assess the clissage construction technique to enable full engineering calculations, a sample shelter would need to be constructed and load tests applied.	
Hazard*	**Performance**
Earthquake HIGH	**UNKNOWN:** Given the lack of engineering data surrounding the clissage technique, the bare walls do not provide a complete lateral load path. Filling the walls with mud will add some lateral capacity, but the increase in weight along with the brittle nature of the finish will most likely not perform well under the cyclical loading typical of an earthquake.
Wind HIGH	**UNKNOWN:** Given the lack of engineering data surrounding the technique, and as with seismic loading, the bare clissage walls do not provide a complete lateral load path. Filling the walls will add lateral capacity, and may provide resistance to wind pressures but could be vulnerable to damage from wind blown debris.
Flood HIGH	**GREEN:** The first floor of the shelter is elevated the surrounding ground surface, and it is easy to modify the design to provide additional clearance if site specific situations required it.
Fire LOW	**AMBER:** The components of the structural system are flammable, and will not offer significant fire resistance. Filling the wall panels would improve the performance of the wall, but offer no protection to the roof. However, the shelter does have two doors.

* See section A.4.5 Performance analysis summaries

Notes on upgrades

Installation of wire or cable bracing to each wall will insure that there is a system to resist lateral loads, and can dramatically improve the performance of the shelter.

To improve overall durability and longevity of the shelter, preservative treated wood could be used. If this option is selected, it is important that all nails, fasteners, and hurricane ties be hot dip galvanized.

Assumptions

- Timber framing is assumed as Spruce-Pine-Fir No 2, or equivalent
- Roof truss top chords are fully braced by the purlins, and the bottom chords are fully braced at mid-span by the bottom chord bracing.
- Lateral foundation loads are resisted by lateral soil bearing on the concrete piers.
- Foundation uplift forces are resisted only by the weight of the shelter, and any frictional resistance of between the piers and soil are ignored.
- There is no building code for Haiti, so this shelter was only analysed using the International Building Code

Potential Issues

Site Selection

- Site selection is the best way to mitigate flood hazards. Select sites on higher ground and away from flood hazards. Provide proper drainage around shelters to prevent accumulation of rain water. Locate shelters a minimum of 10 meters from ravines, or as required by local authorities.
- For sites where soil liquefaction during an earthquake may be a hazard (near river beds, coastal areas with sandy soils and high water tables) the shelter could be seriously damaged in an earthquake.

Materials

- Inspect timber to ensure that pieces are straight, not twisted or bowed, free of knots, and not cracked.
- Cement should be a fine grey powder. If there are larger pieces in the sacks, it is an indication that the cement has at least partially set and may not produce sound concrete.
- Ideal proportions for concrete are 1:2:3, cement:sand:gravel (all by volume). Only add enough water to allow the concrete to be placed. Excess water reduces durability and will cause more cracking of the finished slab. If concrete is mixed in batches, maintain consistent proportions for all batches. See I.3.1 Concrete

Foundation

- Verify that the soil under the piers, concrete slab and masonry walls are free of organic material, and that any soft spots have been compacted. Ground surface should be flat and level prior to concrete placement.
- Provide nails, bolts, spikes, or other protrusions on the end of the wood post encased in the concrete pier to ensure post is adequately anchored .
- Do not dump all the concrete on one side of the slab and push it across to the other side. This will result in most the stone on one side of the slab and the cement on the other. Instead place concrete on the ground in batches to reduce the distance it needs to be moved.
- To ensure sound concrete, slab should be allowed to cure for at least three days before the shelter is installed. Proper curing methods include immersing the slab with water or placing a plastic sheet on top of the concrete.

Timber Framing

- All framing should be adequately screwed together, and screws should not split or crack the wood framing. Verify the proper number of screws are provided and the proper size is used in each connection.
- Verify the truss bottom chord bracing is properly installed, as is required for the roof to resist wind uplift pressures.
- If pressure treated wood is actually used, hot dip galvanized fasteners should be used, as most preservatives are corrosive to mild steel.

Wall and Roof

- Ensure that the corrugated bituminous roofing is properly fixed with suitable screws.

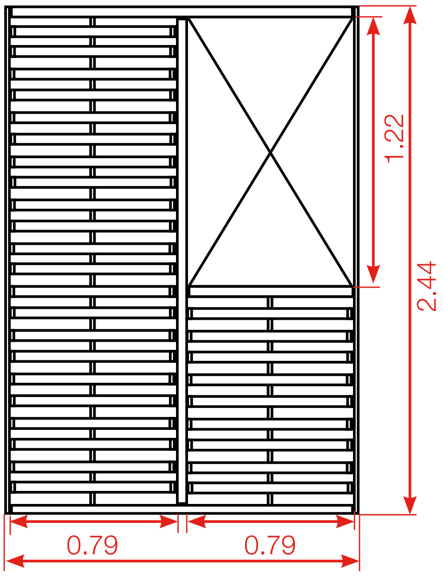
Bill of quantities

The bill of quantities in the table below is for the shelter as it was built, without the design alterations suggested here. It does not take into account issues such as which lengths of timber are available and allowances for spoilage in transport and delivery.

Item	Material Specification See annex I.1	Quantity	Unit	Comments
Foundations				
Portland cement		18	Bags	42.5 kg/bag
Gravel		4	m3	
Sand		6	m3	
CMU blocks	203mm x 203mm x 406mm	90	Piece	
Main Structure				
Timber 2	38mm x 89mm x 4.3m	105	Piece	
Timber 2	38mm x 38mm x 4.3m	5	Piece	
Timber 2	19mm x 152mm x 4.3m	2	Piece	
Timber 2	19mm x 89mm x 4.3m	29	Piece	
Plywood	13mm thick	3	Sheet	1.2m x 2.4m sheets
Covering – Wall and Roof				
Plastic netting	1.2m wide x 30.5m long	0.2	Roll	
Corrugated bituminous roofing (Onduline)		24	Sheet	950mm x 5m
Bituminous ridge Cap (onduline)		8	m	
Door Hinges		1	Pair	
Window Hinges		3	Pair	
Door Lock		1	Piece	
Window Lock		3	Piece	
Hinge Door Lock		1	Piece	
Fixings				
Wood glue		0.4	liter	
Fasteners	25mm x 127mm	30	Piece	
Threaded rod	9.5mm dia x 2m long	5	Piece	
Hex nut & washers	9.5mm dia	100	Piece	
Wood screws	89mm long	40	Piece	
Common nails	127mm long	1.8	kg	
Common nails	102mm long	8.3	kg	
Common nails	76mm long	5.2	kg	
Common nails	64mm long	1.4	kg	
Common nails	51mm long	2.6	kg	
Common nails	38mm long	1.8	kg	
Common nails	25mm long	0.5	kg	
Roofing nails	64mm long	6.4	kg	
Hurricane strap		18	m	coiled

Tools				
Spade		1	Piece	
Hoe		1	Piece	
Wheelbarrow		1	Piece	
Framing Hammer		2	Piece	
Hand Saw		2	Piece	
Socket Set		2	Sets	
Wire Cutters		1	Piece	
Gloves		4	Pair	

Details of a clissage panel



Left drawing of a pre-manufactured clissage window panel and right photograph to show how the wooden slats were woven together. Panels were pre-fabricated and then nailed together on site.