A.4 Checking the structures of transitional shelters

A.4.1 Process

This section discusses how the structural aspects of transitional 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 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.

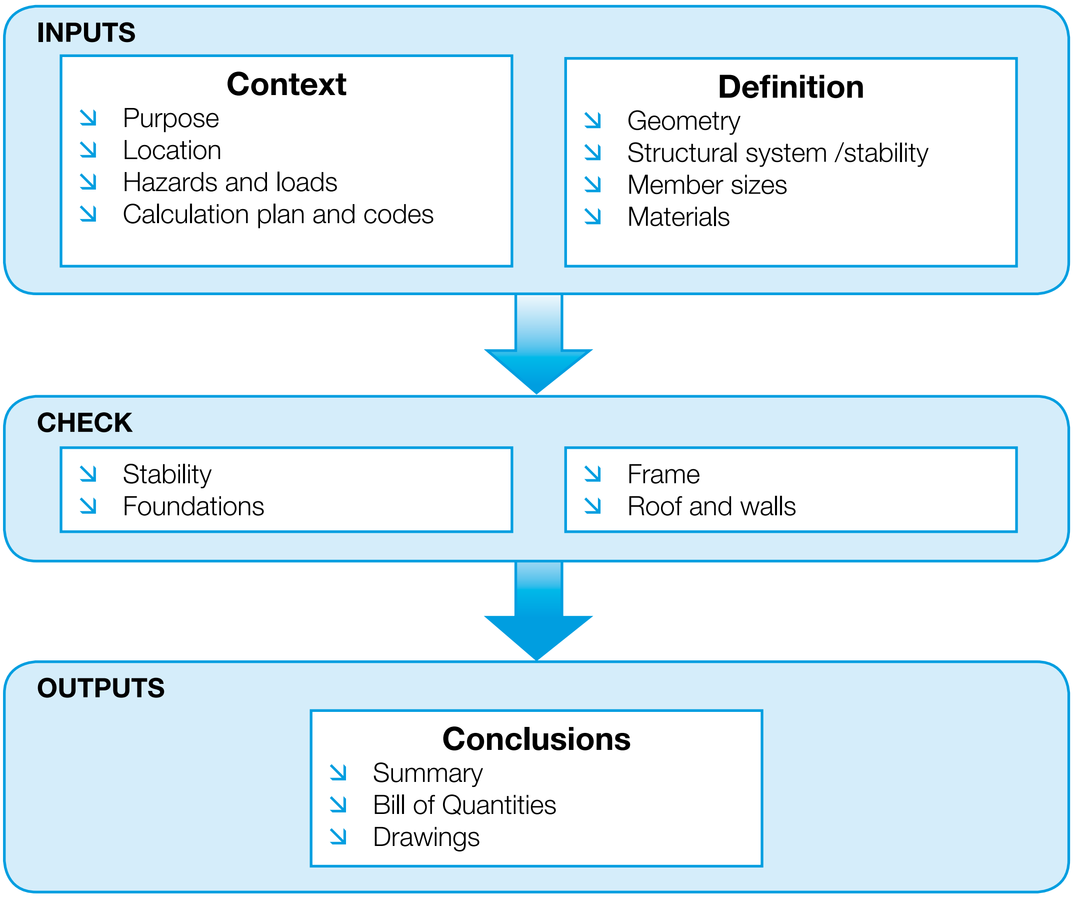


Illustration of the process by which shelters were checked

A.4.2 Approach to codes and standards

Codes used

The 📖[4] International Building Code (IBC) 2009 has been used as a reference for the design checks on the transitional shelters. It is globally recognised and provides a good basis for calculating extreme loading cases such as earthquakes or strong winds. Other building codes (📖[14] Uniform Building Code (UBC) 1997 and 📖[13] National Building Codes & Standards) have been referenced when they are available or appropriate.

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 is safe for habitation. 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 transitional 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.

Applicability of building codes to transitional shelter

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 transitional shelters nor to post disaster situations. To be 'code compliant' every element of a structure must be checked against, and comply with, the criteria set out in the code. As a result, the structures in this book have been checked in the context of code requirements. Key assumptions and reasoning for interpreting the standards are stated in the "assumptions" sections for each shelter review (see Section B).

Shelter upgrades and improvements

Possible upgrades and alterations to improve structural performance are marked on the shelter construction drawings in Section B. Further generic improvements to foundations, walls and roof are summarised in Section C. Such recommendations will not necessarily make the transitional shelter 'code compliant', but they are straightforward measures for improving the performance of the structure.

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 transitional shelter programme.

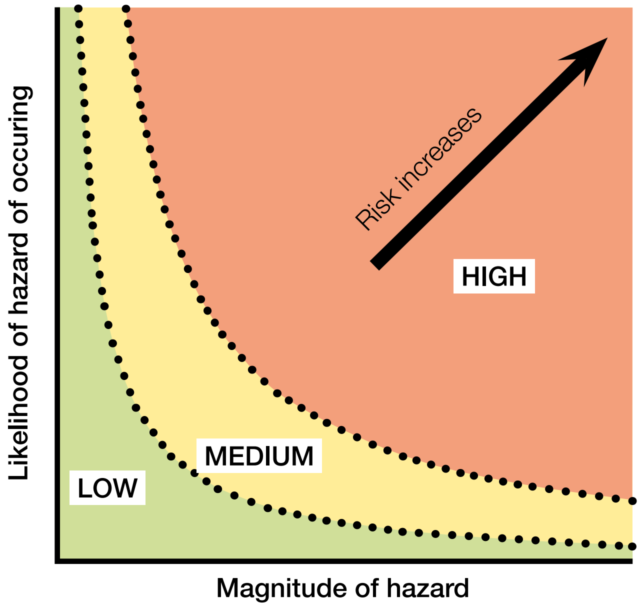
Soil type

For all calculations, a stiff soil type (Soil Profile Type/Site Class D as defined in 📖[14] Uniform Building Code (UBC) 1997 – Volume 2 Table 16-J or '📖[1] ASCE/SEI 7-10 – Minimum Design Loads for Buildings and Other Structures', Table 20.3-1) has been assumed. However, in earthquake prone locations where liquefaction of the soil can occur, specific measures may be required.

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 in various codes and standards as applicable to lightweight, low rise buildings, and statistical assumptions about the likelihood of hazard occurring.



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.

Earthquake

The classification of earthquake risk used in this book is based on the seismic design categories defined in 1 ASCE/SEI 7-10. Design for earthquake loads is derived from the Peak Ground Acceleration (PGA. See Annex 1.4.1 Full Glossary) for a 475 year return period. The PGA is then modified to reflect the soil and building type.

Wind

The classification of wind risk used in this book is based on 14 Uniform Building Code (UBC) 1997. This is expressed as wind speeds which is a parameter that can be used directly in design. These are related to the Saffir SImpson hurricane scale in the table below, which is approximate and for comparison only.

Flood

The classification of flood risk is based on knowledge of historical flood data and local weather effects, and is highly dependent on the local site conditions. Flood damage can be caused by both flash floods and standing water. Each type of flooding has a different impact on structures.

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

* This is based on 📖[1] 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 📖[14] Uniform Building Code (UBC) 1997, Section 1616.

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.

Classification used in Section B for the performance of structures	
Classification	Meaning of classification
GREEN:	Structure performs adequately under hazard loads
AMBER:	Structure is expected to deflect and be damaged under hazard loads
RED:	Structure is expected to fail under hazard loads

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

Performance analysis (example)	
Hazard	**Performance**
Earthquake LOW	AMBER:
Wind MEDIUM	RED:
Flood HIGH	GREEN:

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

Structure is expected to fail under wind loads.

B.6 Haiti (2010) - Steel Frame

Photo: Beatriz Garlaschi for Spanish Red Cross

Summary information

Disaster: Earthquake 2010

Materials: Galvanised steel frame, timber studs, plastic sheeting walls, corrugated steel roof sheeting, concrete foundations, bolts, screws and nails

Material source: Steel frame: imported from Spain, Other materials: sourced locally

Time to build: 2 days

Anticipated lifespan: 24 months

Construction team: Unknown

Number built: 5100

Approximate material cost per shelter: 1700 CHF

Approximate programme cost per shelter: 4300 CHF

Shelter description

The shelter consists of a galvanised rectangular steel frame with an 8.5 degree mono-pitch roof and a suspended floor. The height to the eaves is 2.55m and 3m to the ridge and there is no bracing. The shelter is 3 x 6 m on plan and has 6 columns spaced on a 3m grid, fixed to 800x800x400mm rectangular reinforced concrete foundations using a 300x300x6mm base plate and four ordinary bolts per base. The raised floor is also supported by 13 additional stub columns on 100x100x6mm base plates bearing directly on to the soil. The main structure is three primary frames with rectangular hollow section columns.

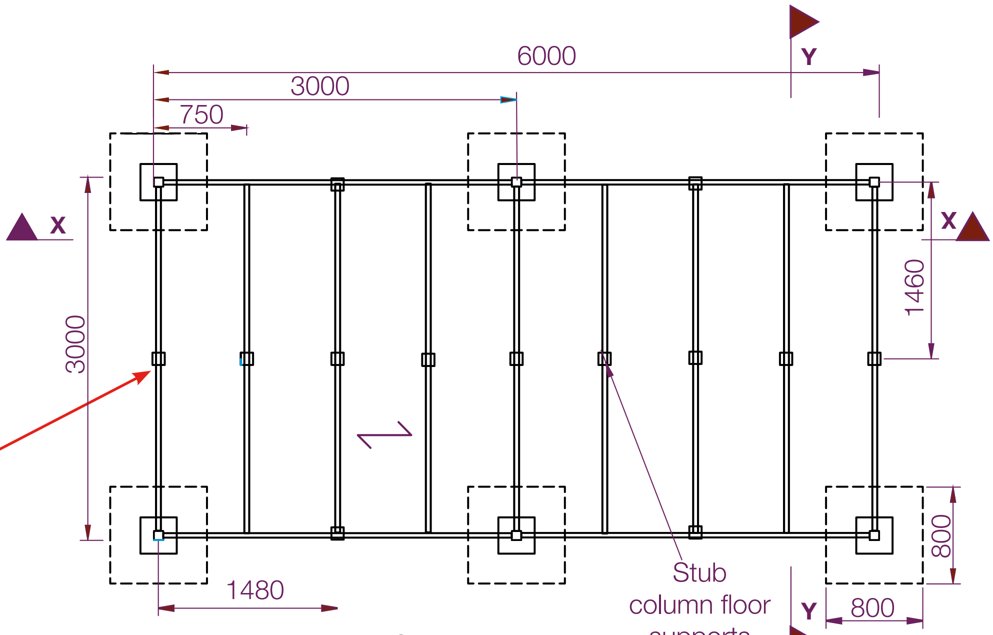
The roof cladding is corrugated steel sheeting nailed to steel secondary roof members spaced at 0.75m intervals spanning between the three primary frames. Timber studs are screwed to the steel members and the plastic wall sheeting is attached to this. Additional timber sub-framing is used to form windows and doors.

Shelter performance summary

This imported, pre-fabricated steel frame solution is relatively expensive, but quick to construct once the materials have arrived in-country. As designed, the steel frame has very limited lateral stability because there is no bracing in the walls or roof. As such, it does not perform well under seismic and wind loading*. Significant alterations are required to improve its performance include modifications to foundations, steel members and bracing in the walls and roof.

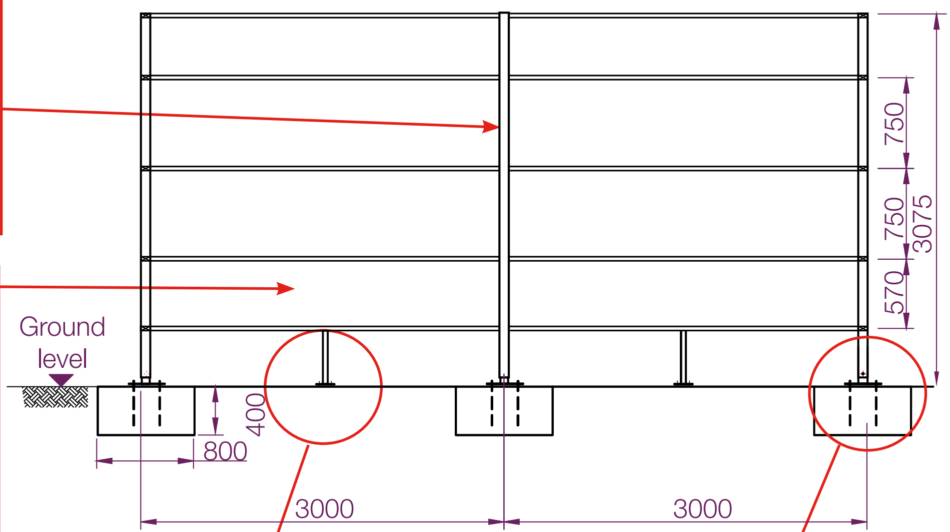
* Note: This analysis is based on higher basic wind speeds than were agreed by the shelter cluster and operational organisations in Haiti - see assumptions below (p58).

Plans and comments



Ground floor plan

CHANGE: Use larger sections for floor joists in order to omit the stub column floor supports.



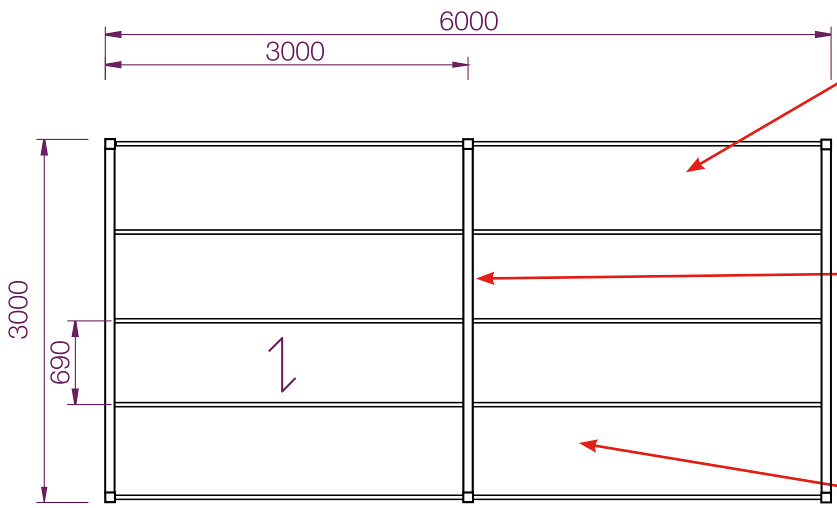
Section X-X

CHANGE: Decrease column spacing for out of plane loads in accordance with design to recommended wind pressures, and increase number of foundations and rafters accordingly.

CHANGE: Lateral stability can be improved by using ½” thick structural grade plywood (plywood 1 annex I.1.3), with vertical framing spaced at 600mm and the plywood with maximum 150mm nail spacing. Alternatively in plane diagonal bracing could be provided. In either case, header and primary floor beams must be strengthened (See Section C.3).

CHANGE: Add concrete pad footings (See Section C.2) underneath the stub column floor supports to distribute bearing pressures on to the soil.

CHANGE: Use an alternative foundation solution to prevent uplift and sliding under wind loads (Embedded base plate or screw in ground anchor - see section C.2). In areas known to have higher local wind pressures, design foundations and member sizes accordingly.

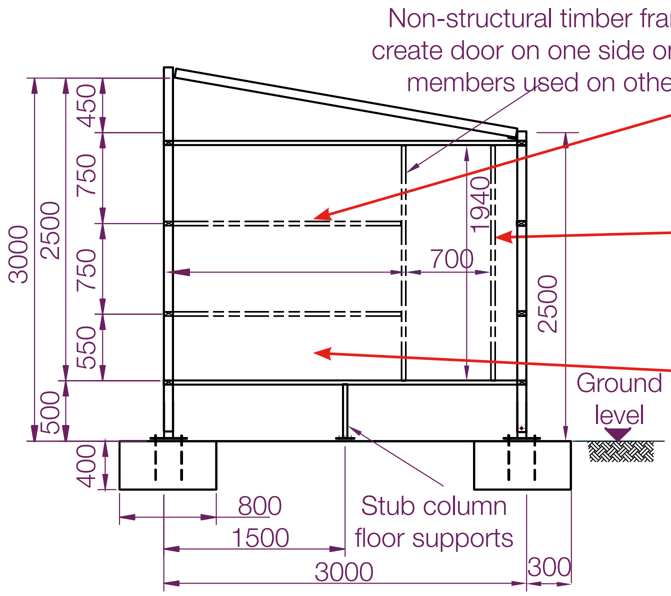


CHANGE: Provide bracing in the roof and securely fasten the roof sheet to the purlins using screws at every crest at eaves and ridge, and every other crest for rows in between (see Section C.4).

CHANGE: Strengthen roof purlins, roof beams and wall transoms to take hurricane wind pressures.

Check: Fasten roof sheet to purlins using screws spread at appropriate intervals (see Section C.4).

Roof Level Plan



CHECK: Connect plastic wall sheeting to the timber studs using 8d nails at 150mm centres all round.

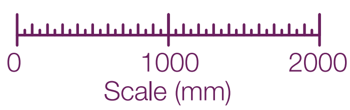
CHECK: Design timber sub-frame to take wind pressures from walls back to steel members and therefore connect adequately to the steel frame.

CHECK: Do not upgrade using masonry or cement blocks due to risk to life, and the increase in seismic force that would be attracted to the structure.

Section Y-Y

CHECK: Provide hurricane straps at connections to secure wooden elements and steel elements against hurricane wind pressures.

CHECK: Check that the soil type for the shelter location is stiff, otherwise design foundations accordingly.



Durability and lifespan

The shelter is demountable with foundation bolts that can be cut to reuse the frame. The intention is to put two shelters side by side to form a double pitched roof structure or four together to use as communal facilities. The frame is durable and has galvanised members. The plastic sheeting will require replacement.

Performance analysis*

Performance of the frame under gravity loads alone is satisfactory. However there is no lateral stability system and it is essential to provide in plane bracing in the roof and walls (see Section C.3). Additional concrete foundations are required under stub column floor supports to take loads and prevent sagging.

Hazard	Performance
Earthquake HIGH	RED: Currently the shelter does not perform well under seismic loads. Bracing is required in the walls and roof to provide lateral stability. The structure is lightweight and relatively flexible posing a low risk to the lives of the occupants.
Wind VERY HIGH	RED: The shelter does not perform well under high wind loads. The shelter should be braced, and the foundation improved. The column spacing should be decreased and the wall supports, roof purlins and roof beams strengthened to take uplift and lateral hurricane wind pressures.
Flood HIGH	GREEN: The shelter has a raised floor to prevent flood damage but no specific checks against standing water have been made.

* See section **A.4.5 Performance analysis summaries**

Notes on upgrades:

The shelter may be upgraded by replacing the plastic sheeting walls with plywood or corrugated metal sheet. To provide resistance to wind pressures, this upgrade would require: In-plane bracing for the roof and walls, concrete foundations under the stub column floor supports, upgraded main foundations (to prevent uplift and sliding), decreased column spacing and strengthened wall supports, roof beams and roof purlins.

If the roof or walls are upgraded with heavier materials, member sizes should be increased and connections strengthened to take the increased gravity and seismic loads. Upgrading the shelter with masonry is not recommended, as collapse of a heavy roof or unreinforced masonry walls would pose a serious risk to life.

If shelter modules are combined to create larger structures, the bracing must remain in the internal walls.

Assumptions:

- A basic wind speed of 217 km/hr* has been assumed along with Exposure Category C ([1] ASCE/SEI 7-10). This is extremely high and it is difficult to resist these pressures in lightweight shelters.
- With more detailed knowledge of the site planning and placement of the shelters, the design wind pressures could be reduced by: intelligent grouping to reduce the Exposure Category to B (with the edge shelters designed for stronger winds) or providing a hurricane shelters designed to withstand full hurricane loads.
- The maximum allowable floor live load is 0.9kN/m^2 and it has been assumed that the roof of the structure will not be subjected to loading from volcanic ash, or sand.
- A stiff soil type (see Site Class D, [4] International Building Code (IBC) 2009) has been assumed. For sites where liquefaction may be a hazard, the shelters could be seriously damaged in an earthquake.
- If the plastic sheeting is nailed to the timber studs using 8d nails at 150mm intervals the columns and wall transoms will fail in bending before the plastic sheeting ruptures or tears/pulls out where it is nailed.
- During manufacture, holes have been made in steel members to connect other elements.
- Foundation base plates are 400*400*6mm thick (see Steel 1, Annex I.1) and are held down to 800*800*400mm plain concrete foundations by four M20 320mm long bolts (see annex I.1).
- It is assumed that all connections are of sufficient strength to transmit forces between members.

* Note: Although this analysis is based on wind speeds of up to 217km/hr, the shelter was designed to resist wind speeds of 140 km/hr with calculations up to 161 km/hr following the standard NBE-EA-95. Shelter cluster technical guidelines for Haiti also indicated peak wind speeds of up to 100mph (161km/hr).

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 available timber lengths and allowances for spoilage in transport and delivery. Steel section thickness does not include galvanised coating.

Item (Dimensions in mm)	Material Specification See annex I.1	Quan-tity	Total	Unit	Comments
Structure - Foundations					
Portland cement (42.5kg bags)	Concrete	3	3	bags	Modify quantity to reflect specification see Annex I.1
Sand	Concrete	-	0.38	m^3	
Gravel (20mm aggregate)	Concrete	-	0.38	m^3	
Reinforcement bars 10mm diameter (L=9.0m)	Rebar	4	4	bars	
Column base plate (300x300x6thk plate, 300 long 80x80x2thk column stub)	Steel 1	6	6	pieces	
Floor support base plate (100x100x6thk plate,435 long 40x40x2 column stub)	Steel 1	13	13	pieces	
Holding down bolts (20 dia. 320 long)	Bolts	24	24	pieces	
Main Structure					
Columns (80x80x2thk, L=3m)	Steel 3	3	9	m	
Columns (80x80x2thk, L=2.55m)	Steel 3	3	7.65	m	
Floor beams (40x40x2, L=2.995m)	Steel 3	4	11.98	m	
Roof cross beams (80x80x2, L=3.0m)	Steel 3	3	9	m	
Secondary Structure					
Floor joists (40x40x2, L=2.9m)	Steel 3	9	26.1	m	
Roof purlins (40x40x2, L=2.88m)	Steel 3	10	28.8	m	
Wall transoms (40x40x2, L=3.0m)	Steel 3	14	42	m	
Window framing (32.5x100, L=0.75m)	Timber 2	8	6	m	
Door framing (32.5x100, L=1.95m)	Timber 2	2	3.9	m	
Timber studs (32.5x100, L=3.35m)	Timber 2	45	151	m	Depends upon arrangement
Plywood door (1.94m x 0.7m)	-	1	1	piece	
Covering – Wall, Roof and Floor					
Plywood flooring (21.8 thick)	Plywood 2	-	18	m^2	
Steel sheeting (0.75m x 1.83m)	Sheet 1	40	54.9	m^2	
Plastic sheeting (6m x 4m)	Plastic	3	72	m^2	
Mosquito net	-	-	9	m^2	
Fixings					
Bolts, nuts + washers (20 dia. 320 long)	Bolts	12	12	pieces	
Bolts, nuts + washers (10 dia. 100 long)	Bolts	99	99	pieces	
Brackets (35wide, 70+20legs, 2 thick)	Steel 3	70	70	pieces	
Bolts, nuts + washers (6.25 dia. 100 long)	Bolts	65	65	pieces	Use unknown
steel angles (75x75x18.75)	-	150	150	pieces	To fix timber framing
Nails (10d)	Nails	1400	9.1	kg	Exact numbers will vary, minimum spacing on drawings

Nails (8d)	Nails	1900	8.2	kg	
Nails (4d)	Nails	3800	5.4	kg	
Hinges	-	3	3	pieces	
Door latch + padlock	-	1	1	piece	
Self tapping screws	Screws	75	75	pieces	Exact numbers may vary, minimum spacing on drawings
Tools Required					
Drill	-	1	1	piece	
Hammer	-	2	2	pieces	
Screw driver	-	2	2	pieces	
Tape measure	-	1	1	piece	
Spirit level	-	1	1	piece	
Plumb bob + 50m gut	-	1	1	piece	
Sockets (to fit 6.25/10/20 dia. bolts)	-	3	3	pieces	
Spanners (to fit 6.25/10/20 dia. bolts)	-	4	4	pieces	
Knitted Gloves	-	2	2	pieces	
Spade	-	1	1	piece	
Hand saw	-	1	1	piece	
Ladders	-	2	2	pieces	