NMBA
National Mission on Bamboo Applications

TRADA

DFID

TRAINING MANUAL

Building with Bamboo

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CONTENTS

- **Preface** **03**
- **Introduction** **04**
- **Species** **07**
- **Harvesting** **08**
- **Selection and Grading** **09**
- **Sizes** **11**
- **Protection by Design** **12**
- **Protection by Preservation** **14**
- **Design** **19**
- **Materials** **22**
- **Tools** **24**
- **Construction Sequence** **26**
- **Construction** **28**
- **Prefabrication** **13**
- **Doors and Widows** **36**
- **Finishing and Maintenance** **37**
- **Demonstration House** **38**

PREFACE

BAMBOO is a durable, versatile, strong and highly renewable material, People and communities in India have known and utilized it for thousands, of year. Millions of people still depend on bamboo for their livelihood, and for household and functional uses. Structural applications of bamboo are a significant part of its traditional use, and hold promise because of the environment-friendly nature, ease of construction and cost-effectiveness of bamboo. They are also important in the context of disaster mitigation and post-disaster rehabilitation.

Provision of shelter for all is high on the country’s development agenda. The National Mission on Bamboo Applications (NMBA) promotes the use of bamboo to provide cheap, durable, functional and easy to construct housing material, to meet shelter needs.

This training manual has been developed through the collaborative efforts of the Timber Research and Development Association (TRADA), UK and the Indian Plywood Industries Research and Training Institution (IPIRTI), Bangalore, and with the support of the Department for International Development (DFID), UK and the National Mission on Bamboo Applications (NMBA), Department of Science and Technology, Government of India.

Designed in a user-friendly format and containing step-by-step descriptions of the process, the manual represents and important step forward in the repositioning of bamboo-based construction, and in the development and dissemination of simple, efficient, durable and tested building technologies.

We, at the NMBA, believe that this manual meets a long felt need.

Vinay Sheel Oberoi
Mission Director
February 2004

01 Introduction

WHY BAMBOO?

Diminishing resources and availability of forest wood and conservation concerns have highlighted the need to identify substitutes for traditional timbers. It is in this context that bamboo assumes special significance.

Bamboo is a versatile, strong, renewable and environment-friendly material. It is a member of the grass family, the fastest growing woody plant on the planet. Most bamboo species produce mature fibre in 3 year, sooner than any tree species. Some bamboos grown up to 1 metre a day, with many reaching culm lengths of 25 metres or more. Bamboo can be grown quickly and easily, and sustainably harvested in 3 to 5-year cycles. It grows on marginal and degraded land, elevated ground, along field bunds and river banks. It adapts to most climatic conditions and soil types, acting as a soil stabilizer, and effective carbon sink and helping to counter the greenhouse effect.

In many areas, bamboo resources have dwindled due to overexploitation and poor management. This issue needs to be addressed through well-organised cultivation, on the lines of homestead, small-holder and plantation-based cultivation. The role of bamboo in community agroforestry as a means of generating income for the rural poor is very important.

Production of bamboo is only the starting point. The real benefits accrue from value-added products. Handicrafts (mats, baskets, tools, toys and utensils) and furniture are established possibilities, produced in finished form or supplied as components to small enterprises for further processing (for example, supply of mats for production of bamboo mat board). There are merging industrial and large-scale application too – in the manufacture of wood substitutes and composites, energy, charcoal and activated carbon. Building and structural components represent vast possibilities for enterprise, value addition, income and employment.

BAMBOO IN BUILDING AND BEYOND

One billion people across the world live in bamboo houses. For the most part, these are low-grade, impermanent building, which do not fully utilize the material properties of bamboo. Many tend to reinforce the image of bamboo as a low-end material. At little extra cost, these buildings can be upgraded to provide safe, secure and durable shelter for the most vulnerable members of society.

Its lack of natural durability contributes to the view of bamboo as a temporary material. Bamboo is susceptible to attack by insects and fungi, and its service life could be as low as one year when it is in ground contact.

However, the durability of bamboo can be greatly enhanced by appropriate specification and design, and by the careful use of safe and environment-friendly preservatives.

The structural advantages of bamboo – its strength and light weight – mean that properly constructed bamboo building are inherently resistant to wind and earthquakes.

A bamboo building need not 'low-cost', nor even look like bamboo! Imaginative design and use of locally available materials within specific cultural context can make the buildings desirable rather that just acceptable.

Bamboo is well placed to address four major global challenges:

- **Shelter security**, through the provision of safe, secure, durable and affordable housing and community building.
- **Livelihood security,** through generation of employment in planting, primary and secondary processing, construction, craft and the manufacture of value-added products.
- **Ecological security,** by conservation of forests through timber substitution, as an efficient carbon sink, and as an alternative to non-biodegradable and high-embodied energy material such as plastics and metals.
- Sustainable **food security** through bamboo-based agro-forestry systems, by maintaining the fertility of adjoining agricultural lands, and as a direct food source – example, bamboo shoots.

The aim of this training manual is to share some of this knowledge – to bring it to the attention of a wider audience and demonstrate with that the new technologies are equally viable in areas which have not had exposure to the 'new thinking'. Above all, it aims to deliver the benefits if promises to the poorest members of society.

BAMBOO: A BUILDING SYSTEM

This manual describes a building system in which bamboo fulfils the main structural role. Round bamboo columns and trussed rafters act as the main loadbearing elements, while composite bamboo grid/cement mortar infill panels act shear walls to resist wind and seismic forces. The system comprises:

- **Foundations**: individual column footings
- **Columns**: bamboo culms set in (or on) concrete footing
- **Floor**: raised by two or three brick courses, filled with rubble and screeded
- **Wall infill**: a grid of split bamboo covered in wire mesh and cement mortar

- **Roof structure**: bamboo rafters or trusses supporting bamboo purlins
- **Roof covering**: corrugated bamboo mat board
- **Doors and windows**: frames of sawn plantation timber with bamboo mat board shutters.

The system satisfies the basic requirements of:

1. **Affordability**: Foundations are minimized, wall panels are non-loadbearing and can be reduced in thickness, and the basic components (bamboo, wire, bolts, chicken mesh, cement) are inexpensive.
2. **Sustainability and environmental impact**: Bamboo is available in commercial quantities through established supply systems. It is a renewable resource with a short rotation period and can be grown on degraded land. It is treated using environment-friendly preservatives. The use of high energy-embodied materials (cement, steel) is minimized.
3. **Cultural acceptability**: The system offers traditional materials in a modern engineering context. The result is homely, with the feel of permanence.
4. **Durability and safety**: All bamboo components are treated with safe preservatives to give extended life; the structure is engineered to resist wind and seismic forces, and other imposed loads.
5. **Improved jointing techniques**: Nailing (and therefore splitting) is eliminated; wiring, bolting and strapping provide positive connections.
6. **Modular construction**: It is suited to both prefabrication and fabrication *in suit*: all components are designed to be prefabricated (examples: infill grids, roof trusses) or prepared on site.
7. **Ease of assembly**: Only basic carpentry, masonry tools and skills are required to undertake construction.

02 Species

SOME 1250 species of bamboo have been identified worldwide. India has around 130 bamboo species, of which the two most widely distributed, *Bambusa bambos* and *Dendrocalamus strictus*, are both well suited to construction. There are many other common species too that can be used in construction, including *Bambusa balcooa, Bambusa tulda, Dendrocalamus asper* and *dendrocalamus hamiltonii.*

Bambusa bambos is easily recognized by its curving, spreading branches covered in spines, usually in threes. *Dendrocalamus strictus* is also a distinctive bamboo, being smaller in diameter and often solid.

Left: *Bambusa bambos* (spiny bamboo)
Right: *Dendrocalamus strictus* (male bamboo)

	***Bambusa bambos* (spiny bamboo)**	***Dendrocalamus strictus* (male bamboo)**
Colour	Bright shiny green when fresh, yellow with age	Pale blue-green when fresh, dull green to yellow with age
Height	15–30 m	8–16 m
Shape	Curving culms	Curving culms above mid-height
Diameter	Up to 150 mm	25–80 mm
Internodes	200–400 mm	300–450 mm
Thickness	Thick-walled	Thick-walled, often solid

The Bamboo species used in construction should meet the basic requirements of sustainability, straightness, diameter, internodal length and wall thickness, as defined in the 'Harvesting', 'Selection and Grading'and 'Sizes' sections of this manual.

03 Harvesting

IF BAMBOO is cut specially for building, rather than obtained from a depot or market, care should be taken to observe good harvesting practices to ensure a sustainable yield.

1. Do not cut culms younger than 3 years.
2. Do not harvest in the rainy season.
3. Do not harvest from a flowering grove.
4. Do not cut lower than the second node, or higher than 300 mm above the ground.
5. Do remove branches, culm tips and all harvest debris. Waste material obstructs growth, encourages disease and makes later harvests more difficult.
6. Do retain leaves for mulch. Their 6 per cent silica helps harden later culms.
7. Do leave a minimum of 6 mature culms uncut in each clump, to sustain grove vitality and ensure a steady yield.

In clumping bamboo, new culms grow around the edge, while the more mature culms are at the centre. One solution is to use the ‘horseshoe’ method, by cutting a narrow path into the grove and harvesting from inside out as the culms mature.

If branches are removed with the use of a machete, they should be cut up-culm, that is, towards the tip. Cutting down-culm tends to scalp the internodes below the branch that is being removed.

NATURAL PROTECTION OF BAMBOO PRE- AND POST-HARVESTING
The time and method of harvesting affect the durability of bamboo. Since starch forms the main food source for insects and fungi, bamboo should be harvested when its starch content is at the lowest, in the dry season. Cut bamboo should be stacked vertically for a few weeks after felling, with branches and leaves intact. Such bamboo will continue to live off its reserves, further depleting the starch. Soaking freshly cut culms in water for several weeks also serves to reduce the starch content by leaching.

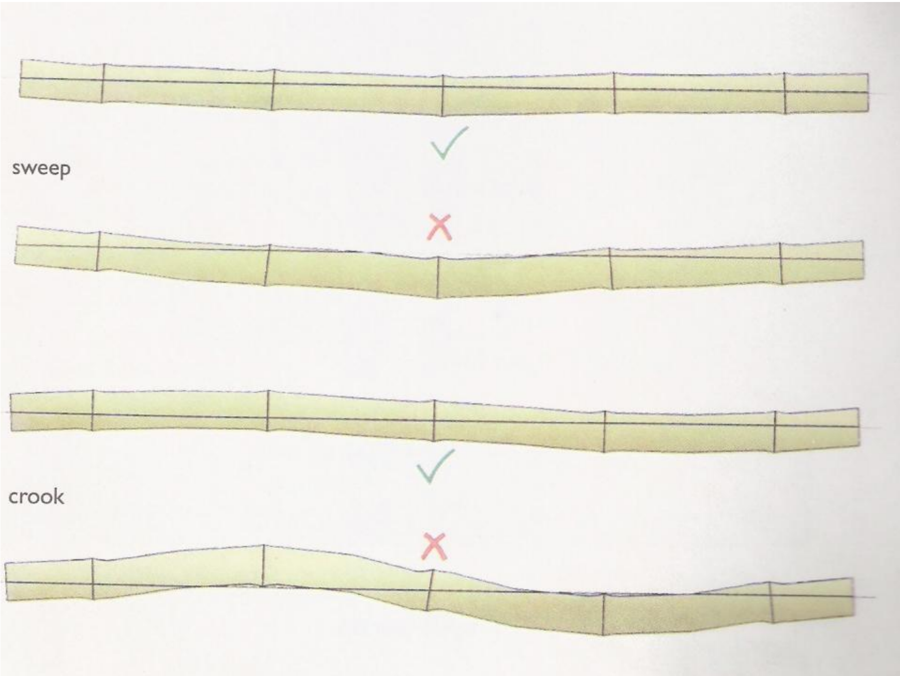
Protection and preservation of bamboo are covered in more detail in the sections titled ‘Protection by Design’ and ‘Protection by Preservation’.

04 Selection and Grading

BAMBOO is a natural material. Its shape, size and quality can vary greatly, even within a given species. To simplify construction, and in order to achieve the best result, a number of elementary grading rules should be applied.

STRAIGHTNESS

In general, the bamboo culms should be as straight as possible. Since culms are rarely completely straight, acceptable levels of 'sweep' and 'crook' may be measured using a stringline. A line stretched between the centres of the tip and butt ends should not fall outside of the culm, as shown below.



TAPER

Taper, or change in diameter over length, should be kept to a minimum. A maximum taper of 10 mm per metre is acceptable for lengths up to 3 m. For example, for a 3 m culm with a 100 mm tip diameter, the butt diameter should be less than 100 + (3x10) = 130 mm. For greater lengths, end-matching may be considered to make the jointing of members as neat and simple as possible.

NODES

Construction is easier if there is a good distance (300–600 mm) between the nodes. However, nodes are strong points, and with careful planning and selection they can be used to good advantage at important joints, as for example in roof trusses.

INSECT AND FUNGAL ATTACK
Bamboo culms showing signs of insect attack of fungal decay should not be used.

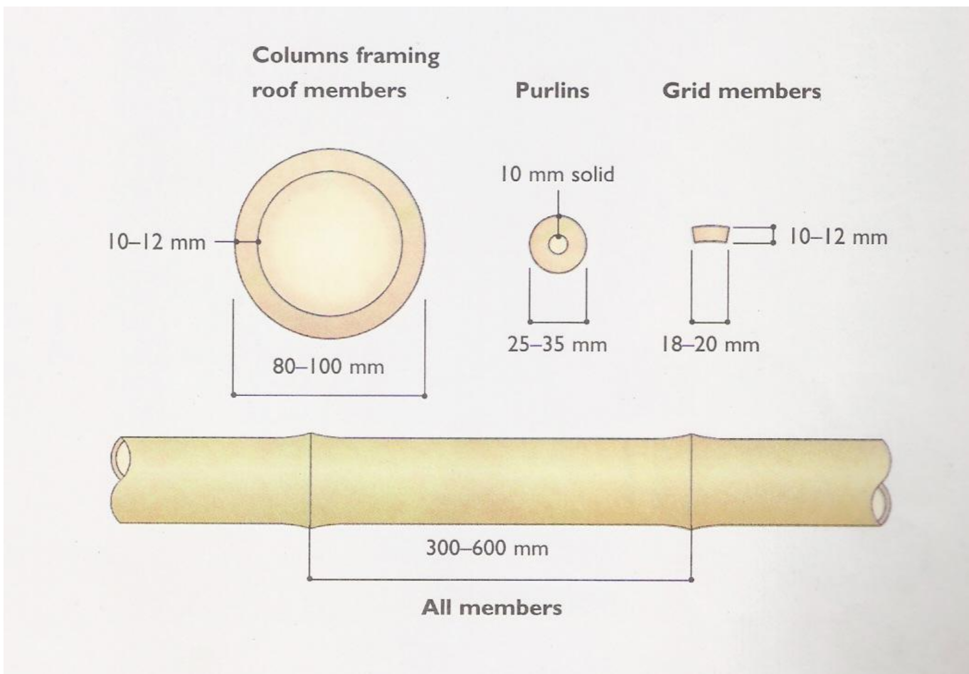
SPLITTING
Most bamboos are susceptible to splitting, sometimes during the drying process but particularly when fixing. Splits should be avoided at or near joints, where they can have a serious effect on strength. It is good practice to cut bamboos longer than required, to allow for end-splitting.

05 Sizes

BAMBOO size are generally specified by minimum (tip) diameter, wall thickness and length. For the type of construction covered by this manual, columns and roof members should be 80–100 mm in diameter, with wall thickness of 10–12 mm.

Similar-sized culms should be used to make bamboo strips for the infill panels. The strips should be 18–20 mm wide and 8–10 mm thick. They can be of random lengths, and cut to size as appropriate during grid fabrication.

For purlins, round-solid or near-solid culms 25–35 mm in diameter should be used.



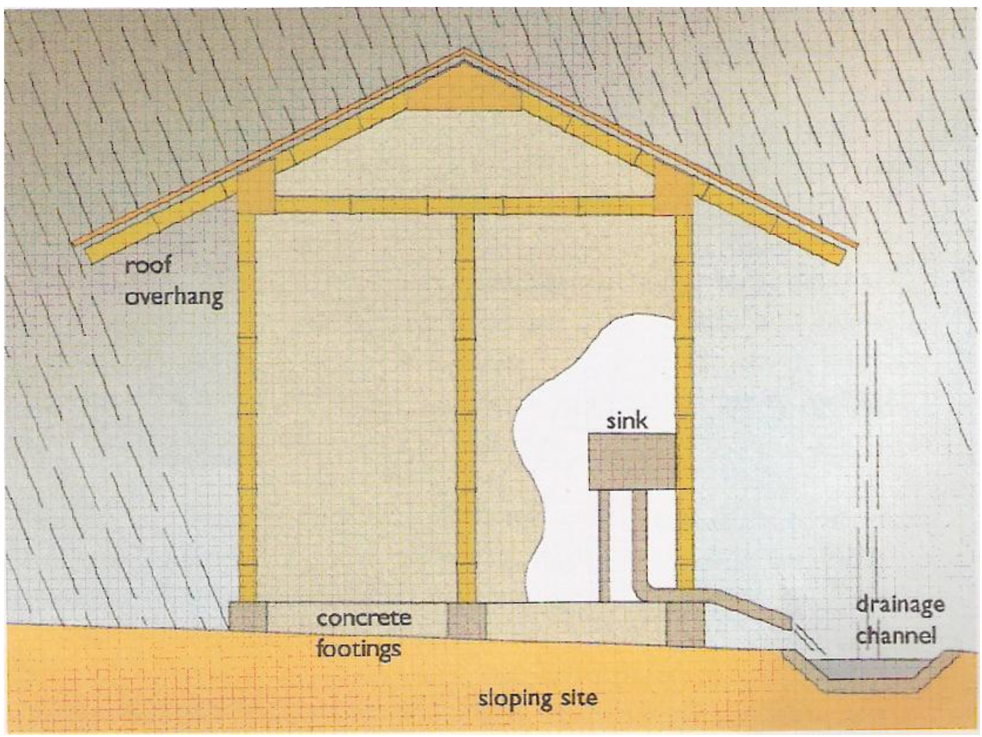
To simplify construction, the distance between nodes (internode length) should be at a maximum, typically 300–600 mm.

Members should be cut longer than the finished length, and cut to size only after drying and/or treatment. The finished lengths should be as defined in the drawings or as required for the particular construction. More details are given in the ‘Demonstration House’ section in this manual.

06 Protection by Design

BAMBOO provides a ready source of food for insects and fungi. It can decay in less than a year when in direct ground contact. Protection is essential to ensure the longest possible life for the material, and for the building in which it is used.

Protection does not necessarily mean chemical treatment. The first line of defence is good harvesting practice (see the 'Harvesting' section). The second is good design. Protection by design involves three basic principles.



1. Keeping the bamboo dry
2. Keeping the bamboo out of ground contact
3. Ensuring good air circulation.

Large roof overhangs prevent direct wetting of walls in heavy and driving rain. Drainage channels and/or gutters can be used to discharge water at a safe distance from the building. The risk of flooding can be reduced by building on a graded or slightly sloping site, and using raised masonry or concrete footings.

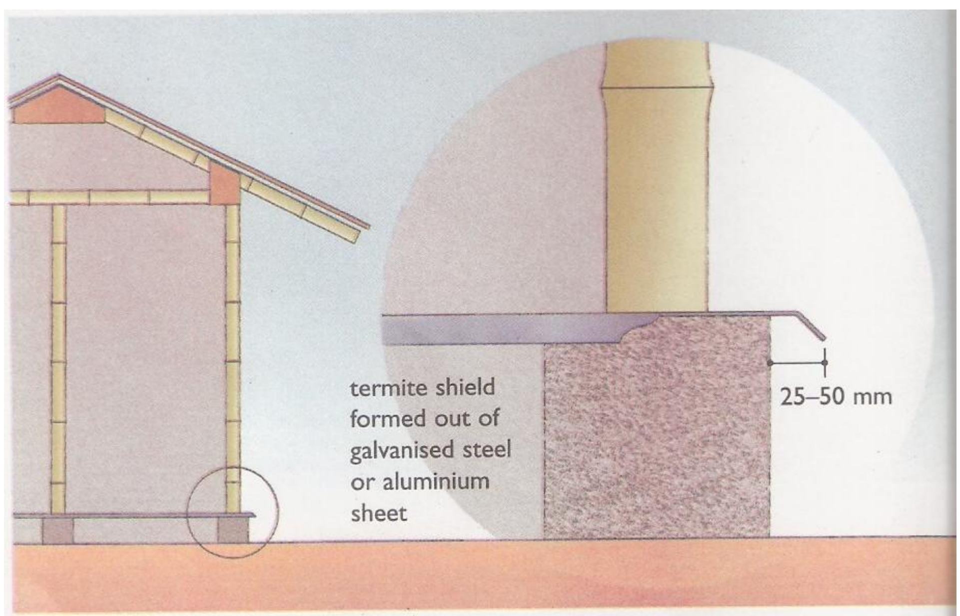
The effects of water inside the building should not be overlooked. Simple provision can be made to drain away washing and cooking water, avoiding the hazards of prolonged wetting.

Where possible, the roof space should be left exposed to improve both visibility and airflow, and aid routine maintenance.

INSECTS AND VERMIN
Raising bamboo columns or wall panels clear of the ground reduces the risk of termite infestation and improves visibility, making inspection easier. Termite shields may be used between the footings and walls, if the risk is considered high. Effective shields can be formed out of galvanized steel or aluminium sheet.

To help combat airborne termites, and the to improve visibility and aid routine maintenance, roof space should be left exposed. If ceilings are used, the roof space should be well ventilated and accessible.

Hollow culms provide possible nesting sites for rodents. Open ends should therefore be plugged. Cavity walls should be avoided.



07 Protection by Preservation

THE SERVICE life of bamboo is governed by its exposure, position and durability, which together dictate the rate of attack by insects and fungi. If attention is paid to design and detailing, the life can be as long as 15 years (see section on 'Protection by Design'). The natural durability of bamboo can be enhanced by a variety of preservation methods, of which the most effective is appropriate use of chemicals. Before reaching a decision about using chemicals, environmental and health effects should be considered alongside the benefits – both special (durable shelter) and environmental (more efficient use of materials).

CHEMICAL PRESERVATIVES

Preservatives are, by definition, toxic to insects and fungi and cannot therefore be 100 per cent 'safe'. However, it is possible to minimize the risk by informed selection and careful use.

Two effective preservatives that are relatively safe, commonly available and simple to use are boron salts and creosote.

Boron (a name for compounds containing borax and boric acid) is colourless, odourless, and relatively harmless to humans and animals (boron compounds are used in soap and fertilizers). However, bamboo treated with boron should not be use where it is subject to repeated wetting, since the chemicals can leach out.

Creosote, a tar oil, is toxic, but its odour, colour and consistency deter misuse. It is extremely water-resistant and can be used in the most exposed conditions.

There are many procedures of treatment with preservative, of which four are described here. These have low environmental impact, are simple and inexpensive to set up, and are suited to small-scale or on-site application. In these methods, preservatives can achieve complete penetration of the bamboo wall, ensuring maximum protection.

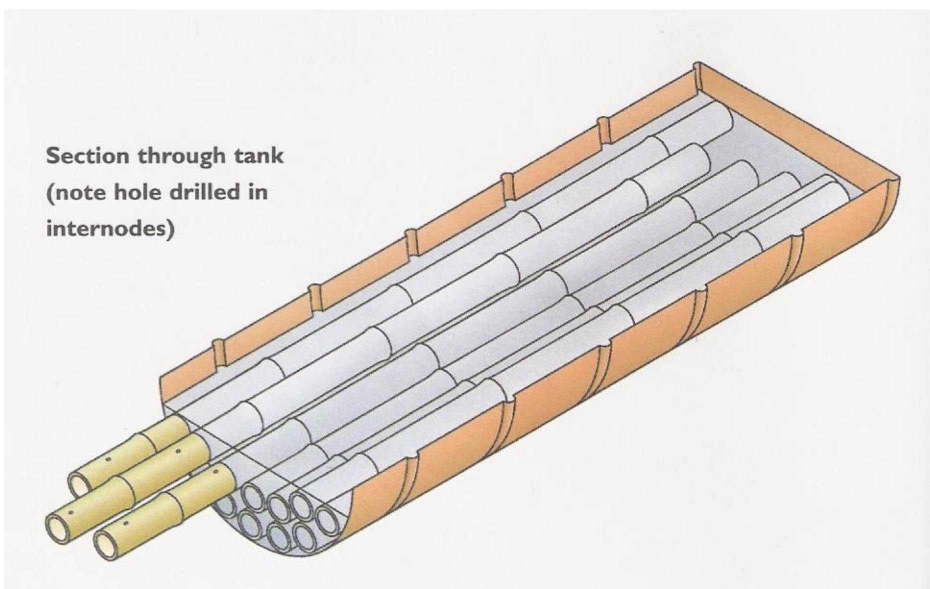
DIP DIFFUSION METHOD

In the dup diffusion method, bamboo culms are prepared to size and then submerged in a solution of water-soluble preservative for several days. The preservative enters the culm through the ends and sides by means of diffusion. This process is suitable for both green and dry bamboo.

A treatment tank for tip diffusion can be fabricated from oil drums that are cut in half lengthwise and welded end-to-end. A 10 per cent borax/boric acid solution can be used as the preservative. Bamboo strips and whole culms can be treated in this way. A 6 mm hole should be drilled between the nodes of whole culms to improve the speed and effectiveness of the treatment.

A good preservative mix would be a 10 per cent solution in water of three parts borax to two parts boric acid. For example, 3 kg of borax can be mixed with 2 kg of boric acid in 45 litres of water. The concentration of the fresh solution can be tested with a hydrometer. A 10 per cent solution should give a reading of between 1.03 and 1.04 – this forms the benchmark for retesting later, and the solution can be used more than once as long as the hydrometer reading is maintained at this level. More borax and boric acid in the proportion 3:2 can be added as required. Bamboo sap and impurities draining into the solution can lead to inaccurate hydrometer reading. After the third or fourth use, the concentration should be increased to 1.040–1.050. When the solution foams significantly and/or a mould forms on the surface, it should be disposed of.

The effectiveness of the treatment can be established by using the spot test. A solution of 10 per cent alcoholic extract of turmeric is sprayed on to a dry cross-section and allowed to dry. A second solution (6 g of salicylic acid in 20 ml of concentrated hydrochloric acid diluted to 100 ml of ethanol) is sprayed on the same area and allowed to dry. A colour change to red indicates the extent of boron penetration.

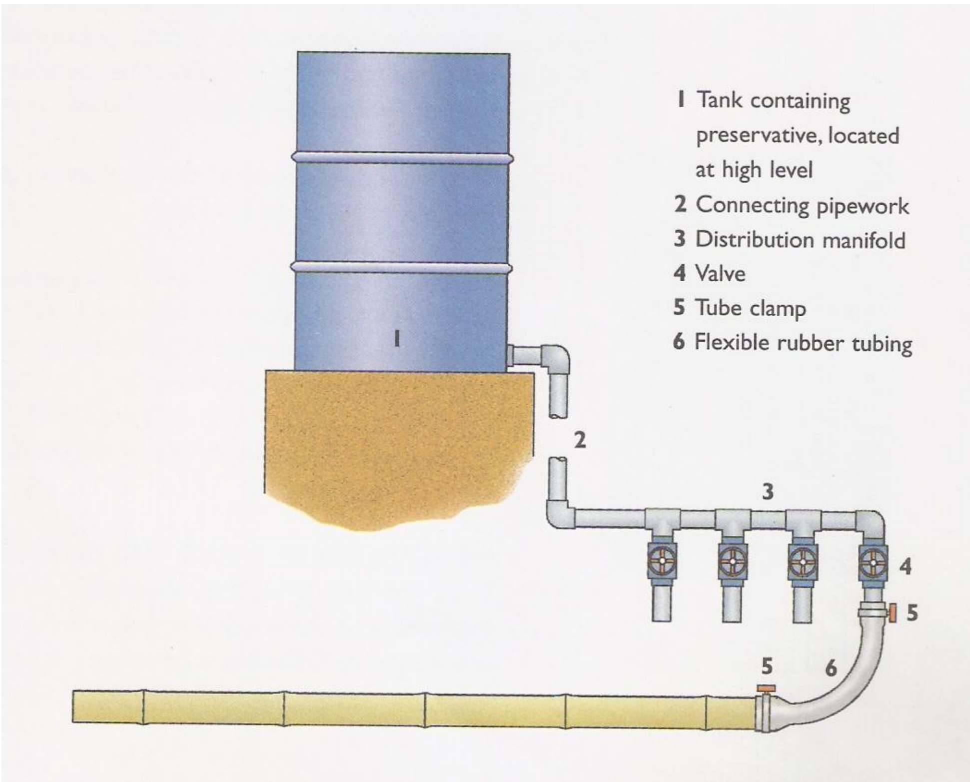


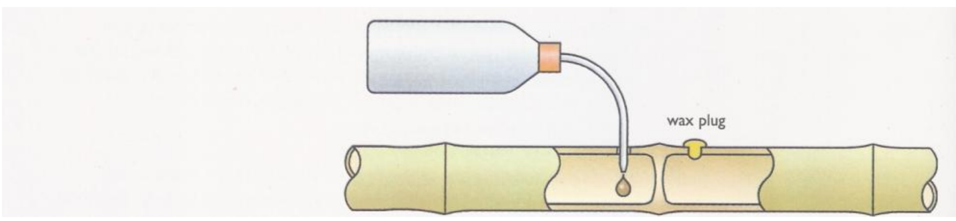
BOUCHERIE PROCESS

In the Boucherie process, a water-soluble preservative is fed under gravity from a tank at a high level through a manifold into the base end or green bamboo culms. The process is terminated when all the sap has been replaced by the preservative. The advantage of this method is that all the water-transporting parts of the bamboo culm, including nodes, can be penetrated by the preservative. However, the bamboo should be treated immediately after cutting.

The equipment for this process cab be fabricated using locally available hardware (oil drum, steel tubed and connectors, valves, rubber tubing and tube clamps). A 10 per cent borax/boric acid solution may be used as the preservative (see ‘Dip diffusion’ for details). The time taken to treat the culms will vary, but is normally 3 to 4 hours.

As a variation, the ‘modified’ Boucherie process introduces pressure into the tank containing the preservative using a foot-pump. This greatly reduces the treatment time. In this case, a pressure-resistant vessel, such as a gas canister, is recommended.



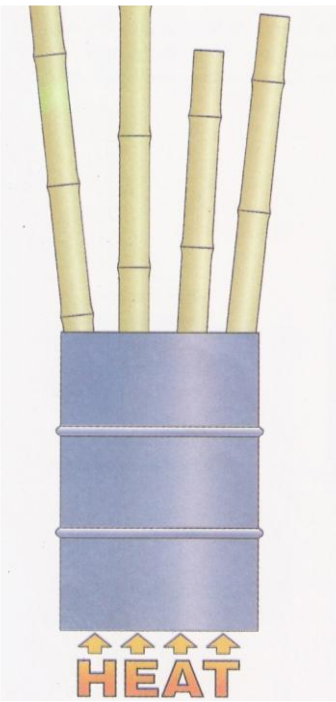


INTERNODAL INJECTION METHOD

This is a simple method requiring little equipment. A 6 mm hole is drilled in each inernode and 20-50 ml of creosote is injected with a wash bottle.

Paraffin wax is used to plug the holes. The culms are then rolled two to three times a day for 7–10 days, to distribute the preservative and complete the treatment.

This method can be used to treat green or dry culms, but preservative penetration may be limited to the nodes. The effectiveness of the treatment can be established by cutting a sample cross-section, where the degree of creosote penetration will be visible. The necessary quantity revealed, by cutting cross-sections through treated test pieces.



Internodal injection is suitable for bamboo members subjected to occasional wetting, such as columns.

HOT AND COLD METHOD
In the hot and cold method, the bamboo to be treated is submerged in a tank of preservative that is directly headed by a fire. After a period of being maintained at a constant temperature, the tank is allowed to cool. During the cooling process, the preservative is drawn into the bamboo.

The hot and cold method can be used for green or dry bamboo culms with either boron or creosote.

It creosote is used this method is ideally suited to the treatment of column ends which are to be buried in the ground. An oil drum can be used to treat the bottom 600–900 mm of several columns at once. The preservative is heated to 90°C for 3 to 4 hours, and then allowed to cool overnight. To economies, or to ensure better distribution of the preservative, the creosote can be diluted up 50 per cent with used engine oil or diesel oil.

HEALTH, SAFETY AND THE ENVIRONMENT
Even relatively safe preservative like as boron can be harmful if used incorrectly or carelessly. The risk to health and environment can be minimized by following a few simple rules:

1. Safety must always come first.

2. The manufacturer's or supplier's safety procedures must be consulted and strictly followed at all times.

3. Premixed and ready-to-use formulations should be used wherever possible.

4. A face mask and eye protection glasses must be worn when mixing preservatives. In addition, safety garments such as gloves, aprons and boots should be worn when working in the treatment area.

5. If the skin comes into direct contact with chemicals, it should be rinsed immediately with clean water.

6. No eating, dirking or smoking should be allowed in the treatment area.

7. Children should be kept away from the treatment area.

8. Freshly treated material should be stored under cover during drying, to avoid rain-leaching of chemicals.

9. The treatment area should be kept clean at all times.

10. Care must be taken to dispose of unused chemicals, empty bags and containers by burying them in designated waste areas.

Note: Borax/boric acid is non-toxic of the environment, but is highly saline. When a moderate amount of it is absorbed into the soil, the ground filters out the salt to the point where it does not pollute groundwater. However, it is safely and out of reach of children. When diluted with more water the discarded solution can be used as a herbicide on terraces and walkways.

08 Design

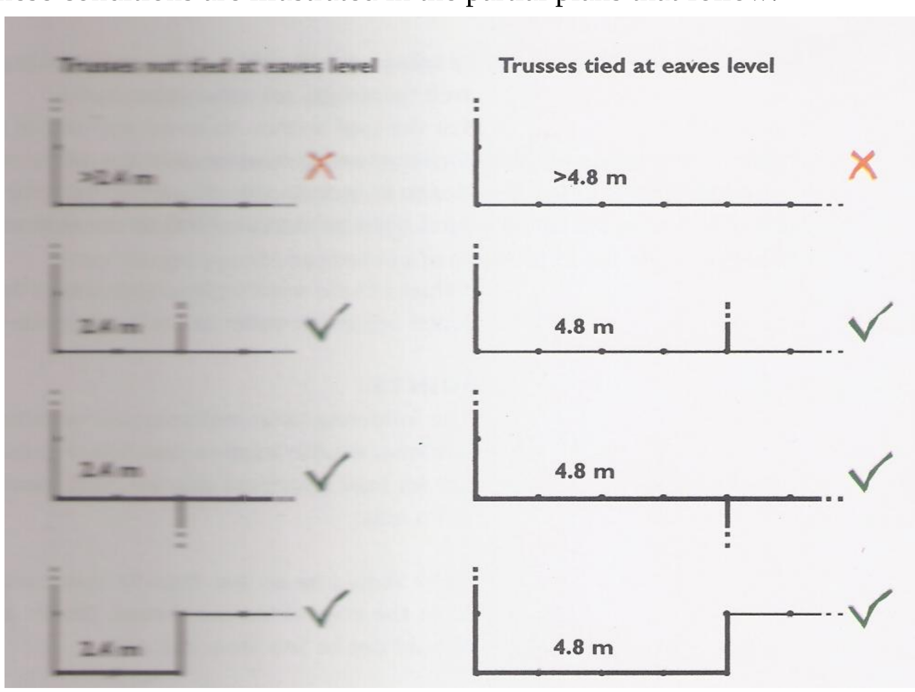
THE BUILDING system is designed to be safe, strong and durable. It is also light, quick and easy to construct. The system is suited to both prefabrication and fabrication *in situ*. For example, all the operations – from cutting to treatment and assembly – can be carried out on site, or the system components can be prefabricated and pretreated in a workshop and transported to the site.

The basic system comprises columns, infill panels and roof trusses. The column (and roof truss) spacing is 1.2 m, and the maximum panel height is 2.4 m. The columns carry the roof loads, and the infill panels resist lateral load such as wind. The use of wire ties, bolts and straps ensures that the entire framework is positively connected, to become a single, composite unit.

WALLS
The modular nature of the system means the wide variations in building shape and layout is possible. The walling system described in the ‘Construction’ section can be used for single-storey buildings up to 4.8 m wide (in the direction of roof span) without the need for further calculation, as long as adequate stiffening is provided to the walls along the length of the building, as follows.

Maximum permissible run of unsupported (with no returns, crosswalls or other adequate forms of bracing) wall
= 2.4 m if trusses/rafters of bracing) wall
= 4.8 m if trusses/are tied at eaves level.

These conditions are illustrated in the partial plans that follow.



ROOF

The examples of roof trusses given in the sections titled ‘Design’ and ‘Construction Sequence’ have been shown to be safe by load test and calculation. Other snaps and configurations can also be proven by tests, or calculated if loadings and properties are known.

Assuming a lower-bound dry density of around 600kg/m^3 for *Bambusa bambos*, the permissible long-term stresses (based on work by Jules Janseen) are as follows.

Bending	7.8 N/mm^2
Axial compression	12.0 N/mm^2 (assuming no buckling)
Shear	1.8 N/mm^2

For example, for dry, round bamboo 80 mm in diameter and 10 mm thick, the *permissible long-term bending moment* is given by:

stress x section modulus = 7.8 x Π (80^3 – 60^3)/32 = 2.3 x 10^5 Nmm
(equivalent to a 47 kg load at the centre of a 2 m simply-supported span: bending moment = 47 x 9.8 x 2000/4 = 2.3 x 10^5 Nmm)

And the *permissible long-term axial force* by:

stress x area = 12.0 x Π (80^2 - 60^2)/4 = 26390 N, or 2.6 tonnes.

However, the full strength of the bamboo culm can rarely be mobilized. For example, deflections often become unacceptable long before the bending capacity is reached, and buckling will generally occur at loads well below the full axial capacity.

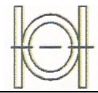
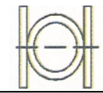
For the roof trusses, to avoid any risk of buckling, unsupported lengths for members in compression should be restricted to 1.5 m. Overall, the design is governed by the strength of the joints, which from the ‘failsafe’ (and most predictable) link in the system.

Values of safe working loads for bolted bamboo/bamboo mat board joints are given under the following sub-heading, ‘Joints’.

JOINTS

The following table indicates safe working loads for joints formed from bamboo, double bamboo mat board gussets and single bolts. The values are for load directions that are both parallel and perpendicular to the culm axis.

Bolts should be no less than 50 mm from the end of the bamboo, or from the edge of the mat board. The in-line spacing of multiple bolts should not be less than 100 mm.

6 mm board 8mm bolt				**6 mm board 10 mm bolt**				**6 mm board 12 mm bolt**			
*t**		*bamboo density**		*t*		*bamboo density*		*t*		*bamboo density*	
	500	*600*	*700*		*500*	*600*	*700*		*500*	*600*	*700*
parallel to culm axis				parallel to culm axis				parallel to culm axis			
8	2.6	2.6	2.6	8	2.7	3.2	3.3	8	3.1	3.7	4.0
10	2.6	2.6	2.6	10	3.3	3.3	3.3	10	3.9	4.0	4.0
12	2.6	2.6	2.6	12	3.3	3.3	3.3	12	4.0	4.0	4.0
perpendicular to culm axis				perpendicular to culm axis				perpendicular to culm axis			
8	0.5	0.6	0.7	8	0.6	0.7	0.8	8	0.7	0.8	1.0
10	0.6	0.8	0.9	10	0.7	0.9	1.0	10	0.9	1.0	1.2
12	0.8	0.9	1.1	12	0.9	1.1	1.2	12	1.0	1.2	1.4
* wall thickness in mm, density in kg/m^3											

9 mm board 8mm bolt				**9 mm board 10 mm bolt**				**9 mm board 12 mm bolt**			
*t**		*bamboo density**		*t*		*bamboo density*		*t*		*bamboo density*	
	500	*600*	*700*		*500*	*600*	*700*		*500*	*600*	*700*
parallel to culm axis				parallel to culm axis				parallel to culm axis			
8	2.3	2.8	3.3	8	2.7	3.2	3.8	8	3.1	3.7	4.3
10	2.9	3.5	4.1	10	3.4	4.0	4.7	10	3.9	4.7	5.4
12	3.5	4.2	4.5	12	4.0	4.8	5.6	12	4.7	5.6	6.5
perpendicular to culm axis				perpendicular to culm axis				perpendicular to culm axis			
8	0.5	0.6	0.7	8	0.6	0.7	0.8	8	0.7	0.8	1.0
10	0.6	0.8	0.9	10	0.7	0.9	1.0	10	0.9	1.0	1.2
12	0.8	0.9	1.1	12	0.9	1.1	1.2	12	1.0	1.2	1.4
* wall thickness in mm, density in kg/m^3											

The loads depend on bamboo wall thickness and density, but are independent of culm diameter.

The loads were derived from a series of tests carried out at IPIRTI. The test programme is described in detail in the IPIRTI/TRADA report TEO/F98002/07 ‘Testing of bamboo-based joints’. Other joint types (single gusset, bamboo-to-bamboo, etc.) are also covered in this report.

09 Materials

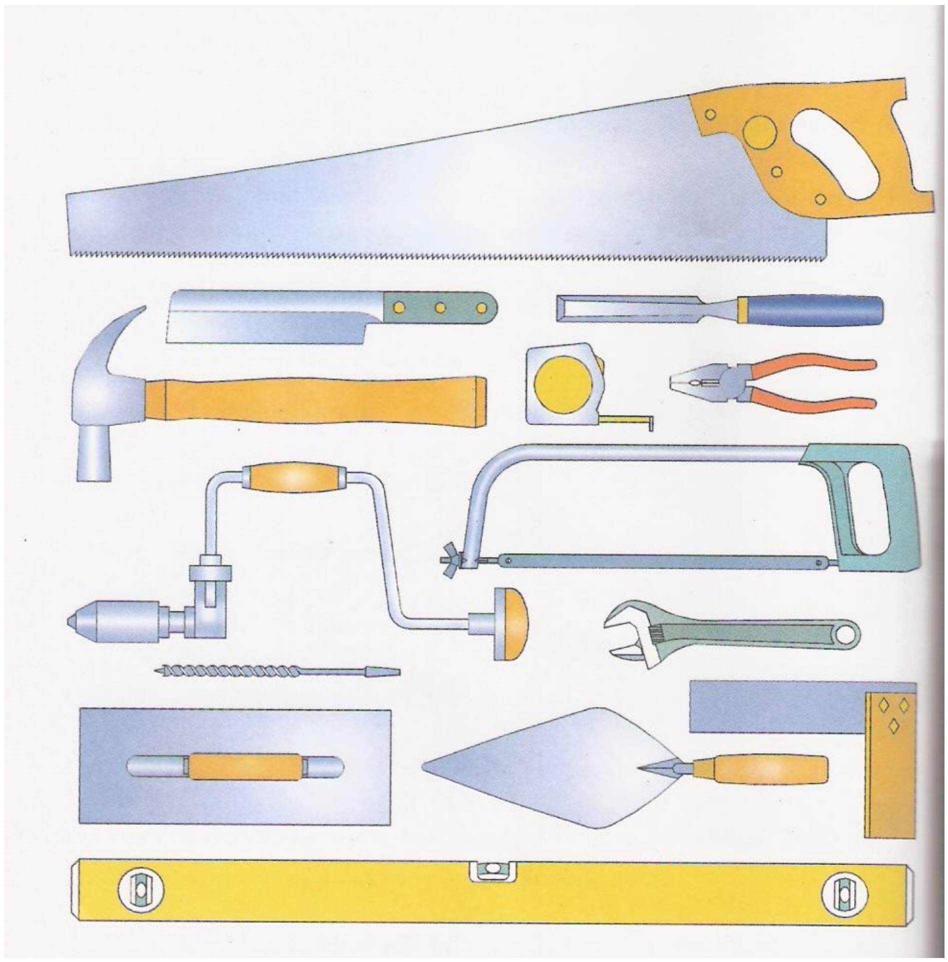
THE FOLLOWING is a list of materials required for construction using the bamboo-based building system, as described in this manual.

- **Bamboo**: 80–100 mm diameter for columns, infill grid, rafters/roof trusses, 25–35 mm diameter fro purlins (more information on size is given under the section titled ‘Sizes’)
- **BMCS** (bamboo mat corrugated sheet) or equivalent: 3 or 4 ply for roofing
- **Plantation timber**: 100 x 38 mm for wallplates and door frames, 75 x 38 mm for window frames
- **Cement/building sands**: for wall infill panels, floor screed
- **Aggregate**: for foundations and flagging
- **Bricks, blocks or cut stone**: for plinth
- **Broken bricks**: for floor infill
- **Chicken mesh**: for wall infill panels
- **MS binding wire**: for wiring bamboo grid, and for fixing purlins to rafters
- **MS reinforcing bar**: 8–10 mm diameter for column anchors, infill grid fixing dowels and optional ring beam reinforcement
- **MS brackets**: 38 x 5 mm for holding down trusses/rafters, and 50 x 6 mm for optional column shoes
- **MS bolts**: 8–12 mm for truss joints, 10 mm for holding down trusses/rafters
- **MS J-bolts and bitumen washers**: for fixing roofing to purlins
- **MS threaded rod**: 10–12 mm for optional anchor bolts and steel shoe fixings
- **Nails**: 75-100 mm for wallplagte, window and door frame fixings to infill grid
- **MS tube**: 50 mm diameter for optional steel shoes..

Notes: Preservative chemicals are covered in the section ‘Protection by Preservation’.

10 Tools

THE BASIC kit of tools necessary for construction using the bamboo-based building system as described in this manual is listed below. Note that this is the minimum requirement – more fools may be added as required and if available.

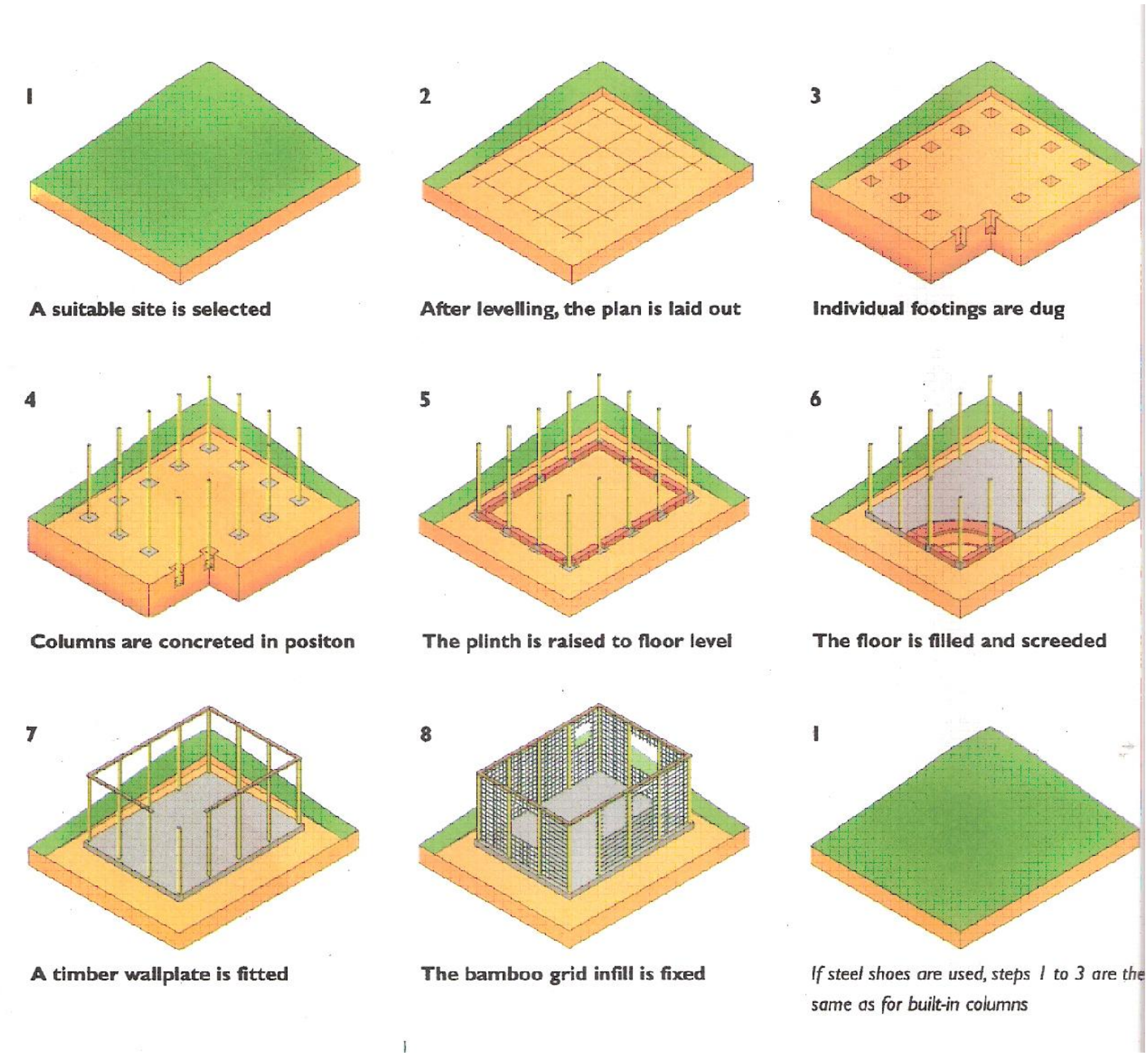


- **Saw**: cutting timber, bamboo and mat board to size
- **Splitting knife**: for cutting bamboo strips
- **Chisel**: for fine splitting, general carpentry
- **Hammer**: for use with splitting knife and chisel and nailing
- **Tape measure**: for setting out and general measurements
- **Pliers**: for cutting and fixing chicken mesh and wire

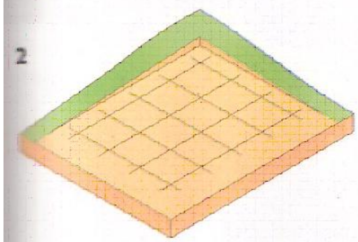
- **Hacksaw**: for cutting steel dowels and small bamboo
- **Drill and drill bits**: for drilling bamboo for dowels and bolts
- **Spanner**: for tightening bolts
- **Plastering trowel**: for floor and wall plastering
- **Bricklaying trowel**: for plinth construction
- **Square**: for general use
- **Spirit level**: for ensuring plumb and level.

In addition, a stringline will be required for checking the straightness of bamboo members (see the section titled 'Selection and Grading') and setting out the foundations.

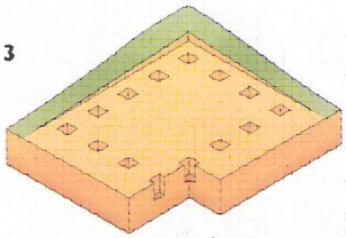
11 Construction Sequence



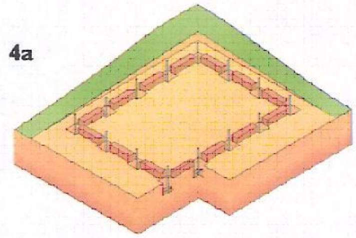
2



3

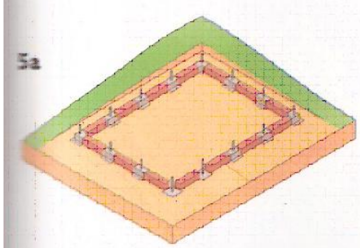


4a



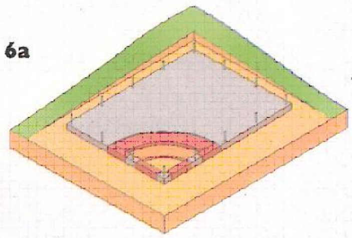
The steel shoes are positioned

5a



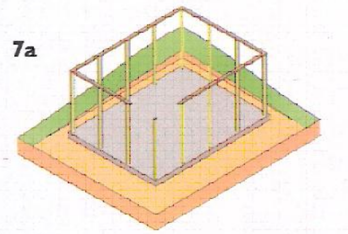
Plinth is raised and shoes concreted

6a



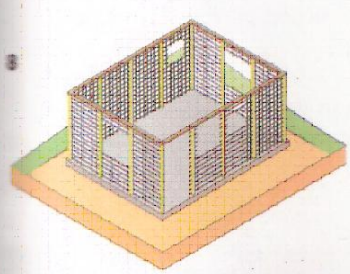
The floor is filled and screeded

7a



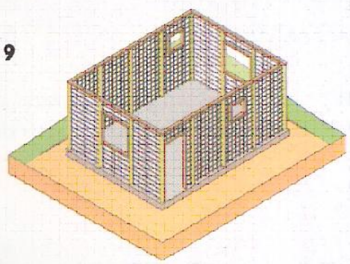
Columns and wallplate are fitted

8



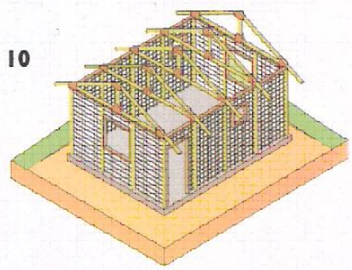
From step 8 the sequence is the same as for built-in columns.

9



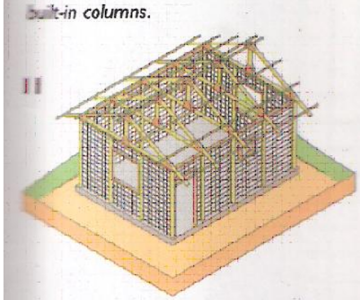
Door and window frames are fitted

10



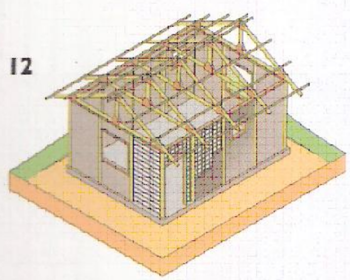
Roof trusses are fixed in position

11



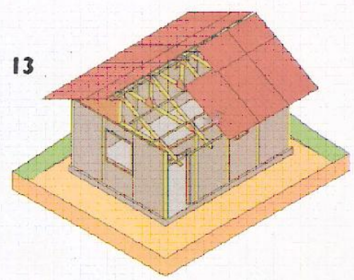
Purlins are bolted to the trusses

12



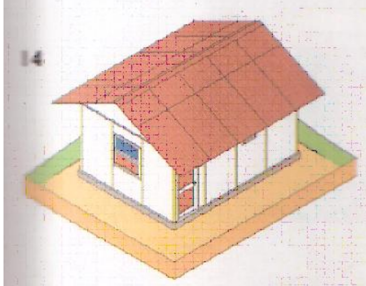
The infill grid is plastered

13

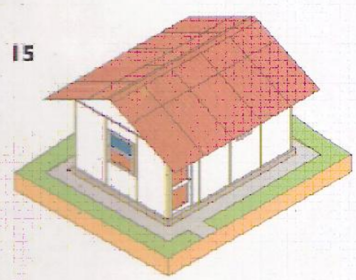


Roofing sheets are Bolted to the purlins

14



15



14 Walls, window and doors are painted

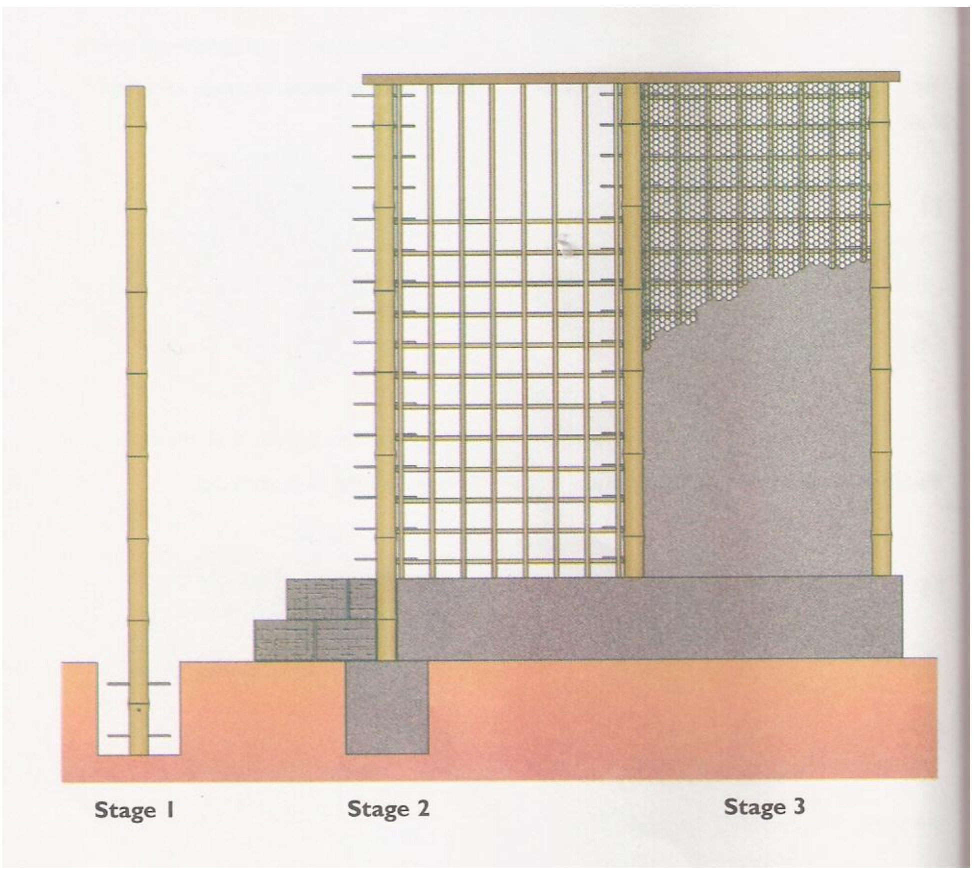
15 With the addition of a flagged area to aid drainage, the building is complete

12 Construction

OVERVIEW
The basic elements and stages in the construction process of walls are illustrated below.

Stage 1: Treated bamboo columns are set in (or on – an alternative base detail using steel shoes is also described in this section) individual concrete footings. The plinth is built up to floor level using bricks, blocks or stone, or with a reinforced concrete ring beam in earthquake zones.
Stage 2: A timber wallplate is fixed to the tops of the columns. Treated bamboo strips are wired to each other and to steel dowels passing through the column.

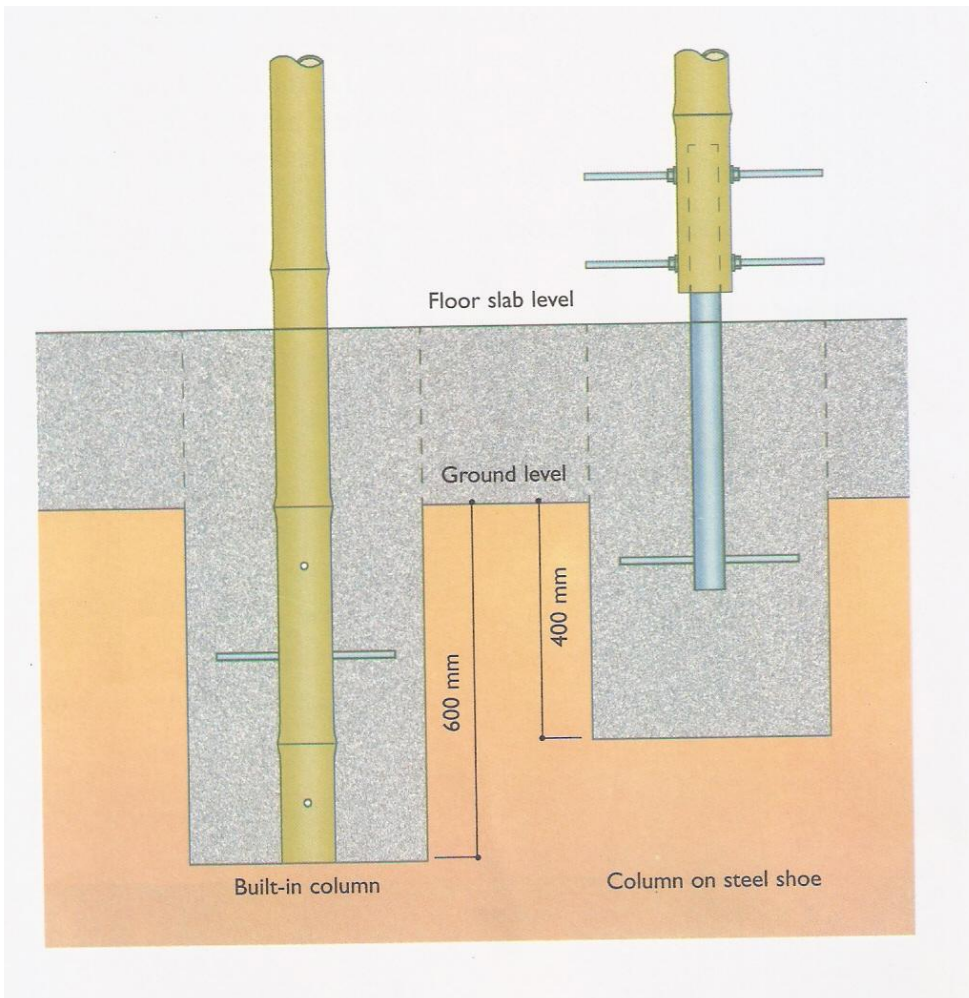
Stage 3: The grid is covered in chicken mesh. This helps to prevent surface cracking and ensures that the mortar remains watertight. Cement render is applied to both sides of the grid to a finished thickness of 50–60 mm.



ON THE GROUND

Site preparation

The ground should be level and even, or graded to provide a slight fall to aid drainage (1 in 100). Organic material should be removed. Made-up or filled ground should be avoided if possible. The foundation sizes apply to undisturbed ground, and an engineer should be consulted if there is uncertainty over conditions. (*Note*: the building system is lightweight and resilient, and therefore more tolerant of slight ground movement than traditional masonry construction.)



Foundations

The building system is very light when compared to tiled and/or masonry structures. As such, extensive foundation work is not required and may be limited to individual footings under each column. Where the column is set in the footing, these should be 400 x 400 x 600 mm deep. Where the column is set on the footing (using a cast-in steel shoe), the footing should be 400 x 400 x 400 mm deep. More foundation details are given the 'Demonstration House' section.

Floor

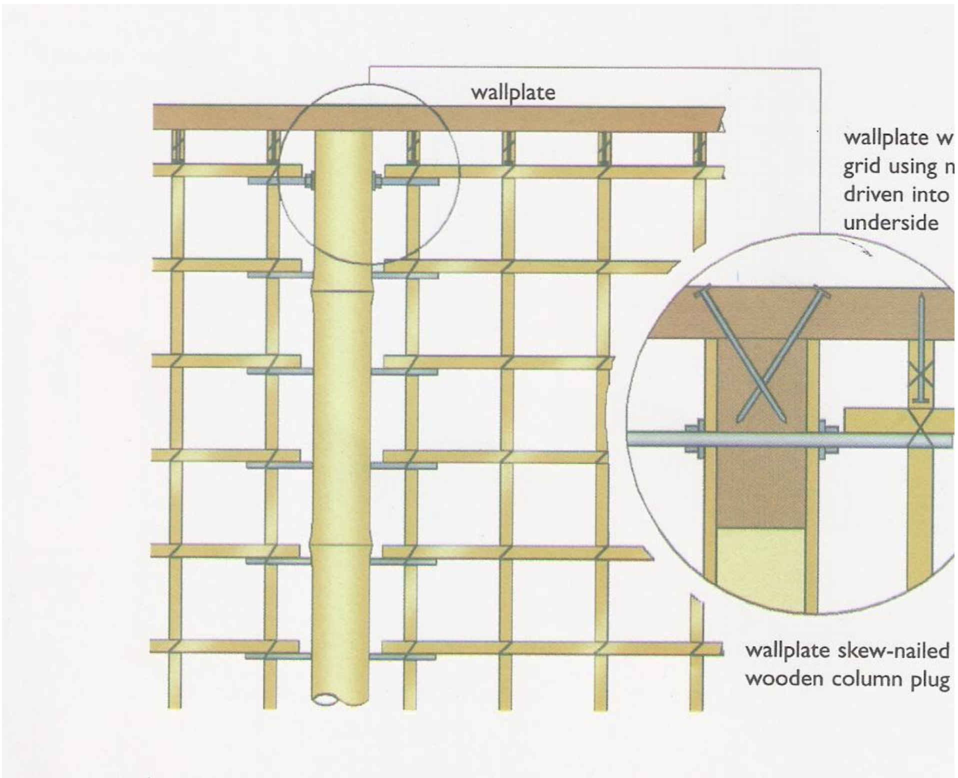
The floor is raised by 200–400 mm above the ground level, using bricks, concrete blocks or stone of define the plinth perimeter. The floor area is then filled with compacted earth, topped with half-bricks and screeded with 20 mm of cement mortar. If the columns are set on steel shoes, the floor can be finished before the columns are installed.

WALLS

Columns

Treated bamboo culms, 800–100 mm in diameter, provide the basic loadbearing framework for the building. The columns are spaced at intervals of 1.2 m and set in (or on) concrete footings.

If the columns are built into the footings, 3 No. steel dowels, 8 or 10 mm in diameter and 300 mm long, are driven through holes predrilled in the base of the column to ensure firm anchorage. If steel shoes are used, the columns are bolted to the shoes using 2 No. threaded rods, 10 or 12 mm in diameter, which double as grid-fixing dowels.



Timber plugs are fitted into the tops of the columns and secured by through-bolting. A plantation timber wallplate, 100 x 30 mm in cross-section, is fixed to the top of the columns by screwing or skew- nailing into wooden plugs.

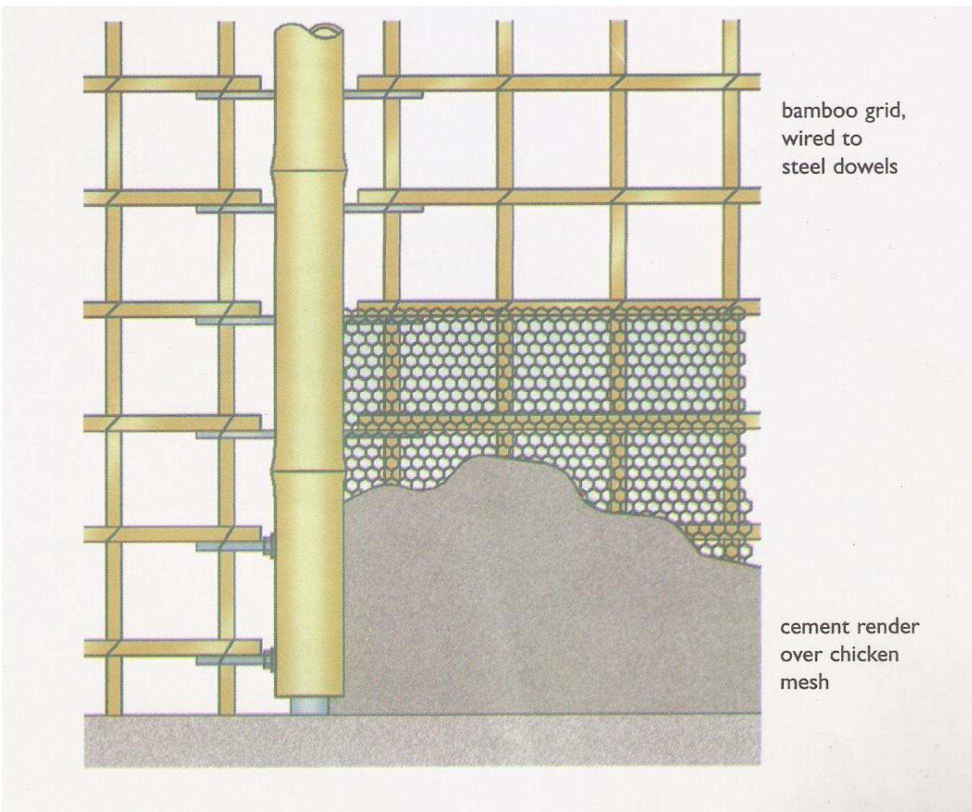
The minimum height from the top of the floor slab to the top of the wallplate should be 2250 mm.

Steel dowels, 8 or 10 mm in diameter and 300 mm long, are driven thourgh holes predrilled in the column at 150 mm centres. The dowels provide anchorage for the bamboo grid infill panel.

For more details on wall construction, see the 'Demonstration House' section.

Wall infill panel
The wall infill comprises a grid of split bamboo, 20 x 10 mm, tied together at 15-mm spacing using mild steel binding wire, and set between the columns. The grid is wired to the steel dowels passing through the columns. The timber wallplate is also wired into the grid using nails driven into its underside.

Note: It is important that all the bamboo strips are set with their smooth face facing outwards.



Chicken mesh is fixed to the outer face of the grid. This helps to prevent cracking of the cement mortar. A 1:3 mix of cement–sand mortar is applied to both sides of the grid to a finished thickness of 50 mm.

More wall panel construction details are given in the 'Demonstration House' section.

Gables can be constructed in the same way. Alternatively, gables can be built up by using a combination of bamboo and plantation timber framing, 4–6 mm flat bamboo mat board, louvers and glazing, as required.

ROOF

Roof structure

The roof comprises bamboo trusses at 1.2-m spacing, located over the columns. A suitable roof pitch is 1 in 2 (this simplifies the setting out of components). The trusses are made from 80–100 mm diameter bamboo. Joints are formed using 6–9 mm mat board gussets and 8–12 mm diameter bolts. A simple 2.4 m span truss is illustrated below.

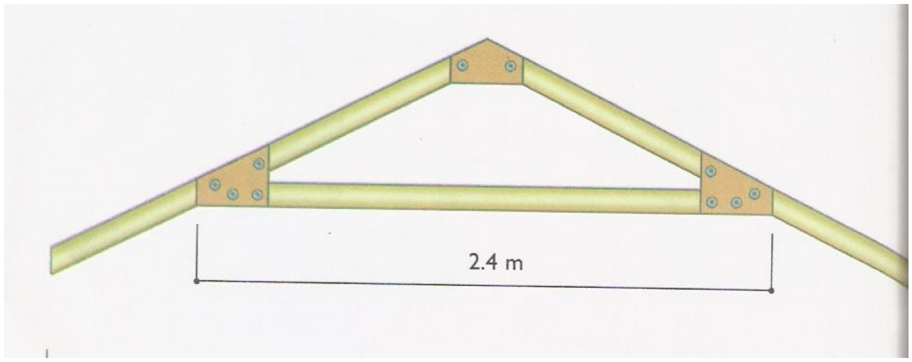
The strength of larger trusses can be established by calculation, if the properties of the components are known, or by load testing. Design guidance and values of safe working loads for bolted bamboo/bamboo mat board joints are given the 'Design' section.

The trusses are fixed to the wallplate using steel brackets to resist wind uplift. Small diameter (25–35 mm) bamboos are used as purlins, and are fixed to the rafters using J-bolts. The spacing will depend on the roof covering. For bamboo mat corrugated sheet, up to 1 m spacing is possible.

Details of a 4.8 m, span truss, with various options for wallplate fixing, are given in the 'Demonstration House' section.

Roof covering

The 3-mm bamboo mat corrugated sheet, developed by IPIRTI, offers a strong, lightweight cladding solution with good insulating properties. Alternatively, galvanized corrugated steel or aluminum sheet can be used, laid on top of a flat bamboo mat board that forms an insulating layer. In both cases, the roof covering can be fixed using J-bolts and bitumen washers.


2.4 m

13 Prefabrication

ONE OF the main advantages of the building system is that all the components can be prepared at the site where construction is to take place. For example, house can be built using locally grown bamboo, which is cut, treated and assembled on site using simple tools and inexpensive equipment. However, this *in situ* method of construction may not always be the most efficient or cost-effective. If several houses are planned, perhaps at different sites, then prefabrication may be a option.

Prefabrication has several obvious advantages:

- The time required on site is minimized
- The batch production of components is more efficient
- Better repeatability and quality control can be achieved through the use of jigs and templates
- Production of components can take place where resources (example, bamboo and workers) are available
- Skilled labour is centralized; semi-skilled workers can be supervised
- Expensive machinery (example, splitting machines) becomes cost-effective
- Hazardous processes (example, preservative treatment) can be centralized, thereby increasing safety and reducing environmental hazard
- Production can continue during the rainy season in covered facilities.

The bamboo-based building system described in this manual is designed such that the main components can be prefabricated and pretreated in a workshop and transported to the site as a kit.

- The columns can be supplied cut to length with packing pieces, grid-fixing dowels and anchorage dowels prefitted.
- The bamboo infill grid can be make up into panels of the required size.
- Roof trusses can either be fully assembled or supplied as components (examples, precut rafters, ties and gusset plates).

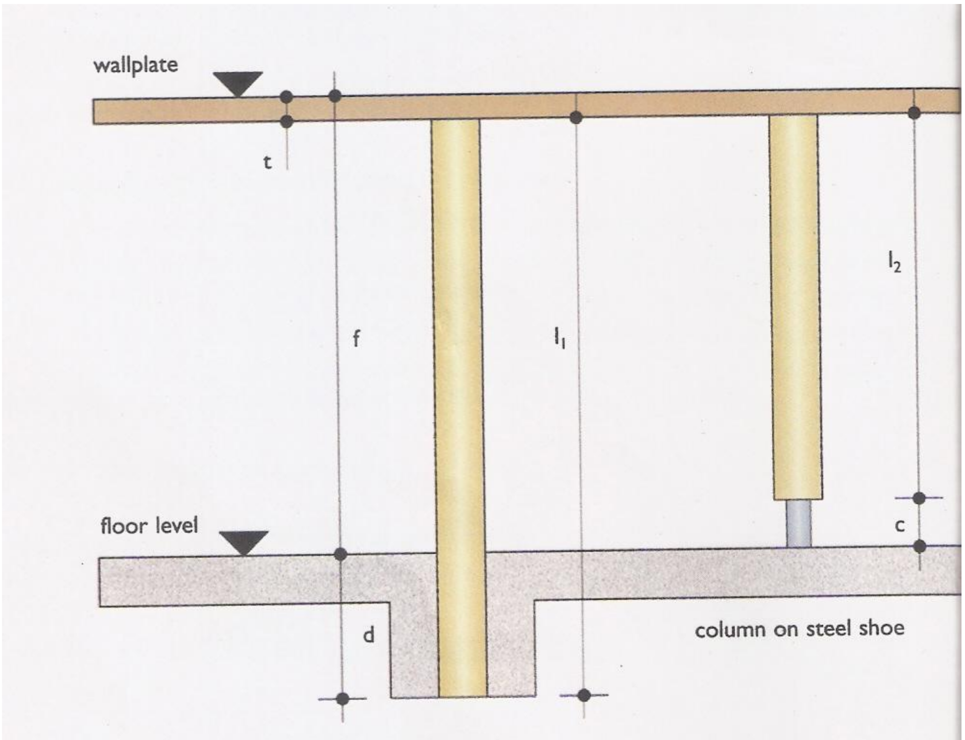
For the columns, the finished length will depend on two main factors: the floor to wallplate height, and whether they are built into a footing or sit on a steel column base. This is shown diagrammatically below.

Thus, for built-in columns the total length l_1 will be given by:

$l_1 = d + f - t$ where d = depth of footing below finished floor level
f = floor to wallplate height
t = wallplate thickness.

And for columns on a steel base, the total length l_2 will be given by:

$l_2 = f - c - t$ where f = floor to wallplate height
c = clearance between column base and floor
t = wallplate thickness.



It is essential that the tops of the columns are all at the same level once fixed. This requires a combination of precise cutting and very accurate leveling (particularly of foundations if the columns are built-in). It is therefore easier to supply the columns 50-100 mm over the required length, and then cut them to finished size once installed, with the aid of a stringline at wallplate level.

For the infill panel, the bamboo strips can be wired together to create a panel that will fit between the columns.

In this case, the width of the panel w will be given by:

$w = s - d - 2c$ where s = column spacing, centre-to-centre
d = column diameter
c = clearance between column and grid (around 20 mm).

And the height of the panel h will be given by:

$h = f - t - 2c$ where f = floor to wallplate height
t = wallplate thickness
c = clearance between floor/wallplate and grid.

Note: If during installation there is a mismatch between horizontal grid members and column dowels, the dowels can be wired to the first vertical grid member instead of the horizontals.

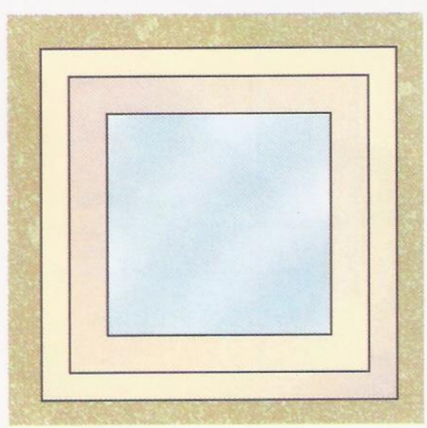
14 Doors and Windows

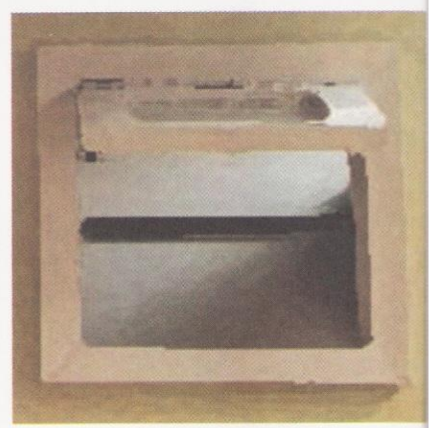
FRAMES
Door and window frames are made from sawn, treated timber obtained from sustainably managed plantations. Reduced sizes are possible with most good-quality timbers. This, together with simplified sections, ensures minimum usage and wastage of material.

Door and window frames are fixed firmly into the building framework either by bolting to columns, or by wiring into the bamboo infill grid before plastering, using nails driven into the outer perimeter as fixing points. Once fixed, timber cover strips are used to seal the joint between the frame and column, or frame and plasterwork, as appropriate.

DOORS
The doors are paneled in bamboo mat board. A minimum thickness of 6 mm is recommended for internal use, and 9 mm for external doors.

WINDOWS
Window shutters are framed in timber, and can either be paneled or glazed. For the paneling, bamboo mat board can be used: 2-ply (3 mm) mat board is adequate for small areas, but 4 mm float glass can be used, but 6 mm safety glass is recommended.





LOUVERS
As an alternative to opening shutters or fixed glazing, louvers can be used. Louvres provide airflow and light, while at the same time offering improved security, and protection from direct sun and driving rain. Louvres can be made from 4 mm or 6 mm mat board, mounted in small aluminum channel sections nailed to the inside of the frame.

Door and window construction is covered in detail in the 'Demonstration House' section.

15 Finishing and Maintenance

PAINTING
Infill panels can be finished the outside using traditional lime wash or cement paint. Cement paint is available in a variety of colours, which can be used to good effect to brighten up the exterior. Internally, distemper can be used.

Exposed bamboo and woodwork can be economically finished on the inside and outside with semi-transparent cashewnut shell liquid varnish (CNSL). Internally, the exposed mat board can be finished with colorless cardinal-based varnish. Alternatively, bamboo and woodwork can be painted with conventional oil-based paints.

MAINTENANCE
If careful attention has been paid to protection (both by design and preservation) and the quality of construction, the maintenance required will be minimal.

The interior and exterior should be regularly inspected for signs of damage, insect attack or decay. Remedial treatment can be applied to exposed bamboo and woodwork (example, preservatives by brushing), and to the infill panels (example, replastering for local damage, cementitious paint for hairline cracks).

Regular repainting will prolong the life of joinery items such as windows and doors.

If bamboo mat corrugated sheet roofing is used, refinishing with CNSL is recommended but not essential (the predicted life of the material is 25 years). However, it is important to keep the roof clear of leaves and other debris that could trap water.

16 Demonstration House

THE WORKING drawings contained in this section relate to the 20m2 (200ft2) house first constructed on the IPIRTI campus in Bangalore. The drawings, when read in conjunction with the background information contained in all the previous sections, should provide enough information to enable a skilled carpenter and mason (with supporting labour) to construct a house that is similar in all important respects.

DRAWING SCHEDULE

Series A: Building plans
A1 Plan at slab level
A2 Plan at window sill level
A3 Plan at roof level

Series B: Building elevations
B1 Front and rear elevations
B2 Side elevations

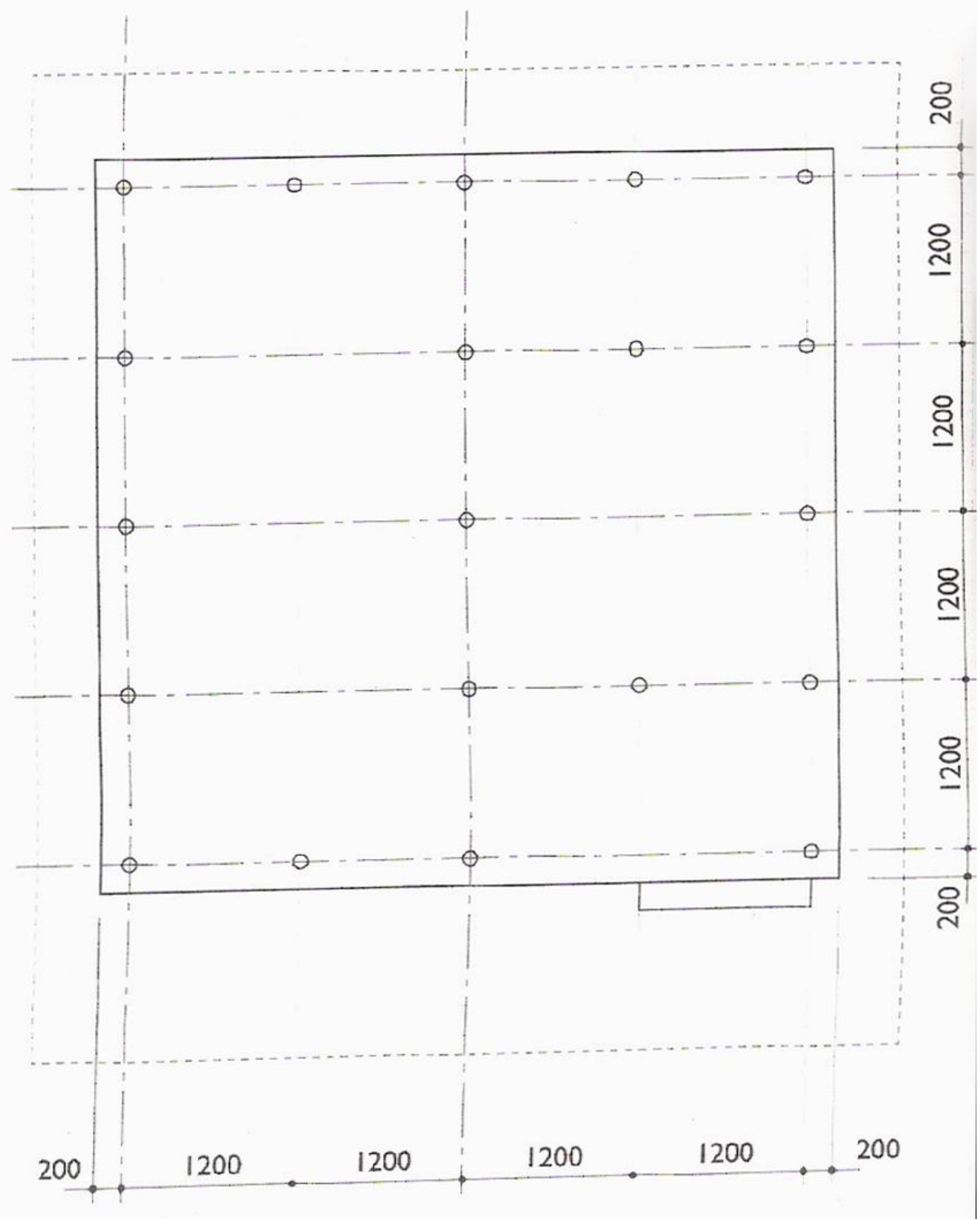
Series C: Building cross-sections
C1 Cross-sections

Series D: Foundation and floor details
D1 Footing details
D2 Ring beam details
D3 Plinth and floor details
D4 Column base details

Series E: Wall details
E1 Wall panel construction

Series F: Roof details
F1 Roof truss type t1
F2 Roof truss type t2
F3 Rafter holding down details

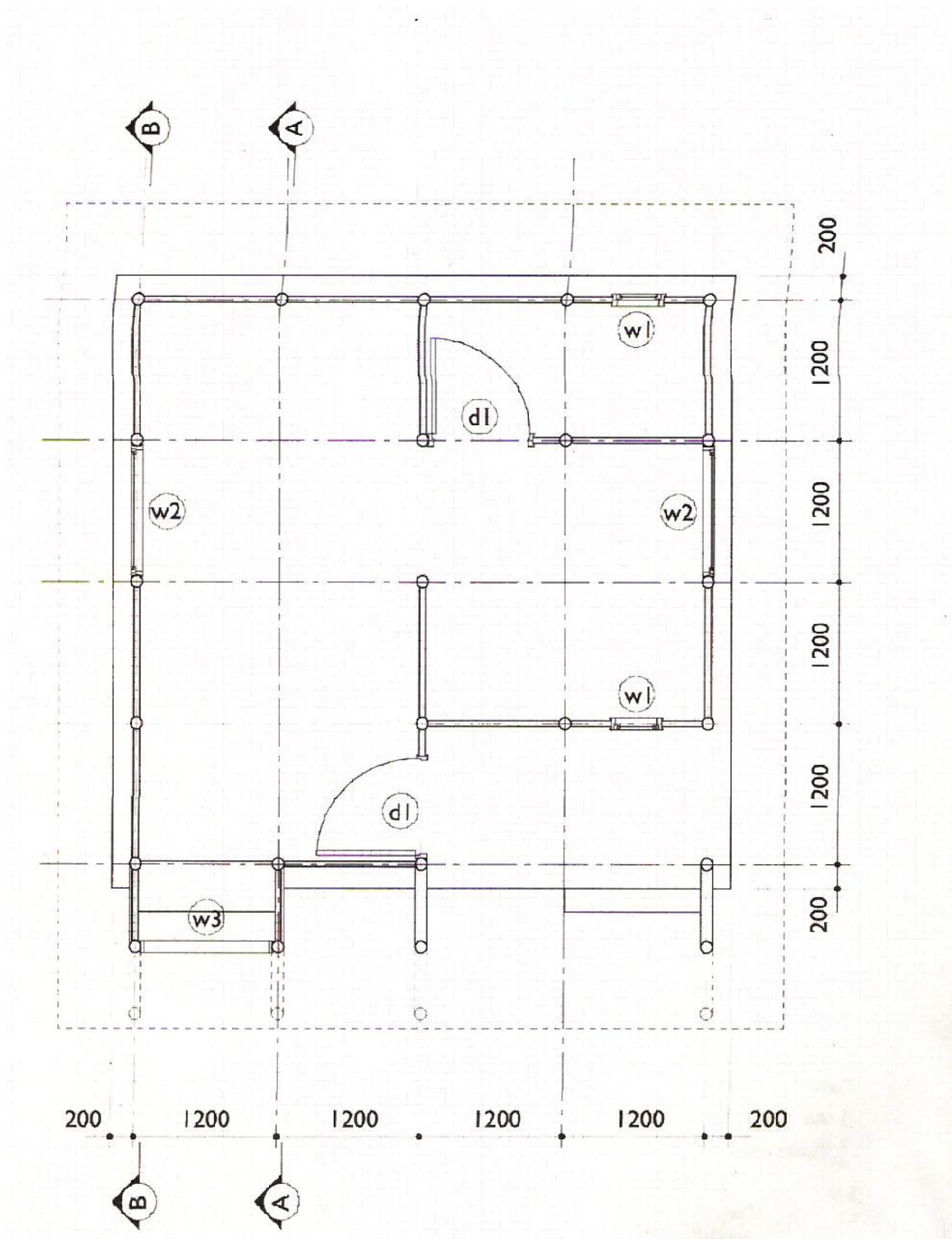
Series G: Joinery details
G1 Door construction
G2 Window construction
G3 Door and window details



Plan at slab level
Drawing number A1
Scale 1:50

Notes

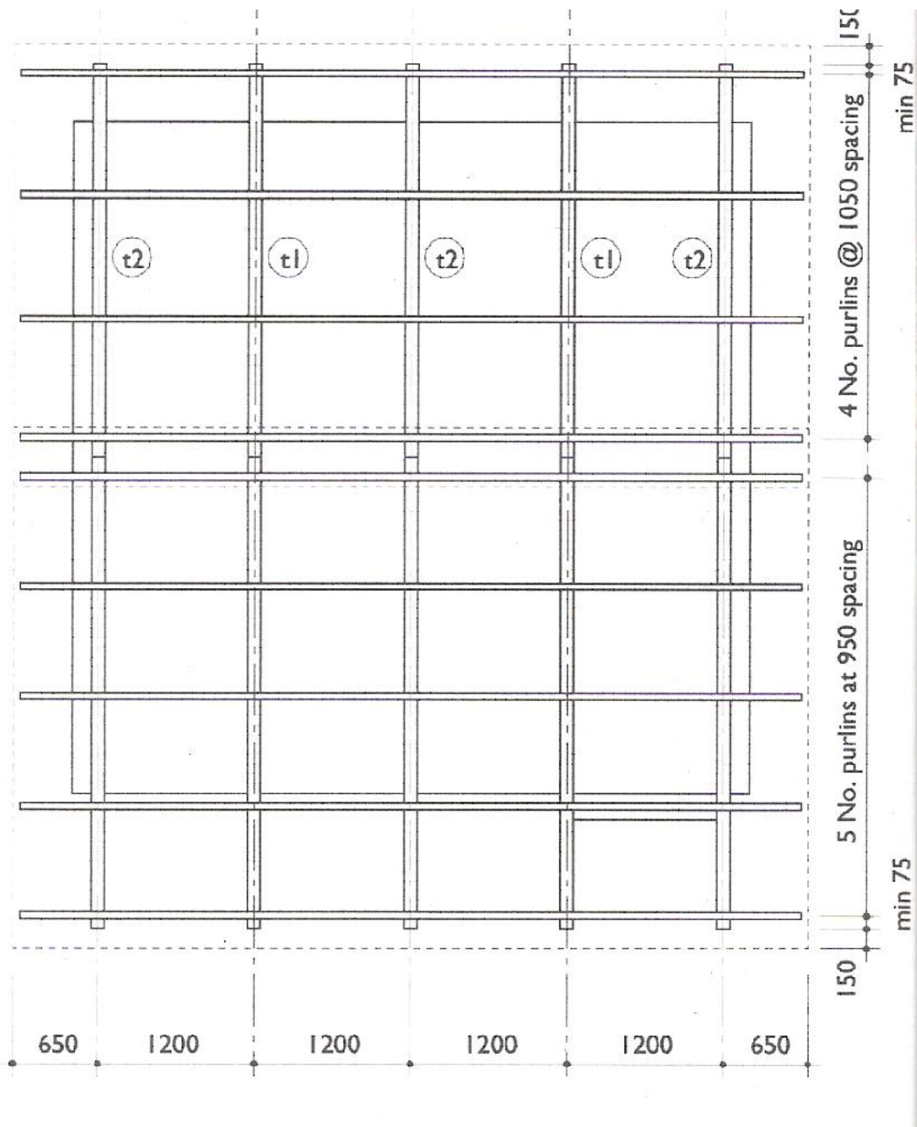
1 All dimensions in mm unless noted



Plan at window sill level
Drawing number A2 Scale 1:50

Notes

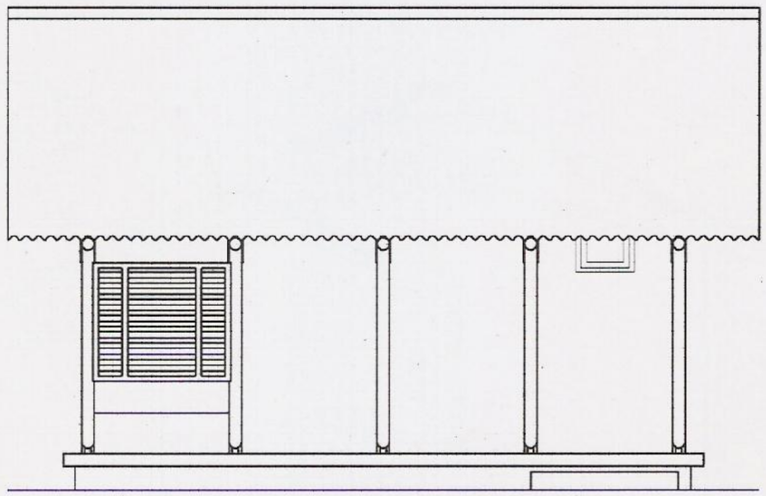
1 All dimensions in mm unless noted
2 For sections see drawing number **C1**
3 For door and window details see drawing numbers **E1**, **E2** and **E3**



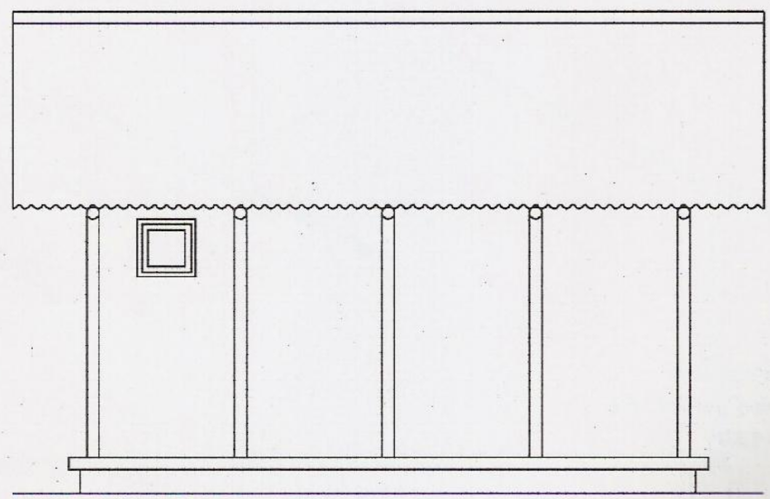
Plan at roof level
Drawing number A3
Scale 1:50

Notes

1 All dimensions in mm unless noted
2 Purlin spacings measured on slope
3 For truss details see drawing numbers **D3** and **D4**



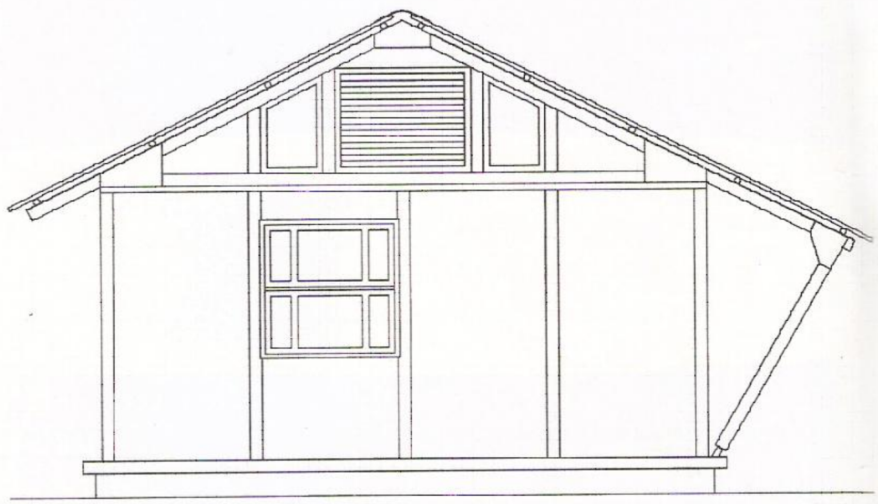
Front elevation



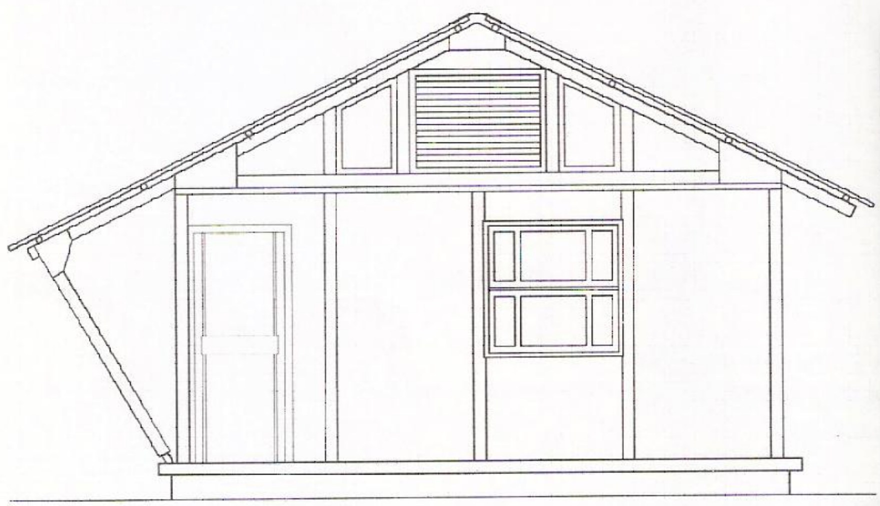
Rear elevation

Front and rear elevations
Drawing number B1
Scale 1:50

Notes
1 All dimensions in mm unless noted



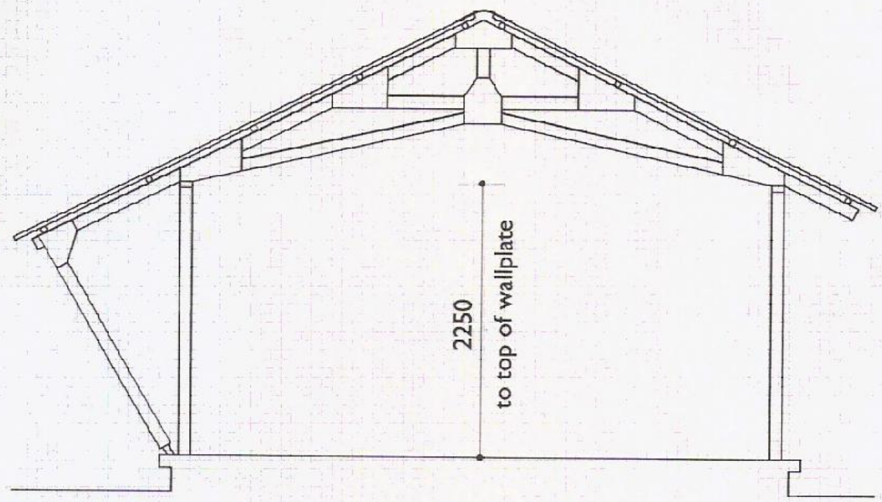
Left elevation



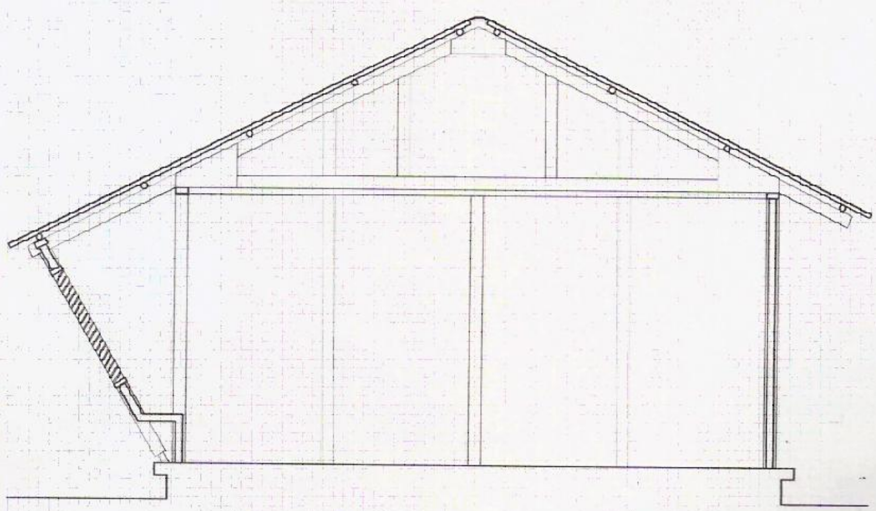
Right elevation

Side elevations
Drawing number B2
Scale 1:50

Notes
1 All dimensions in mm unless noted



Section AA

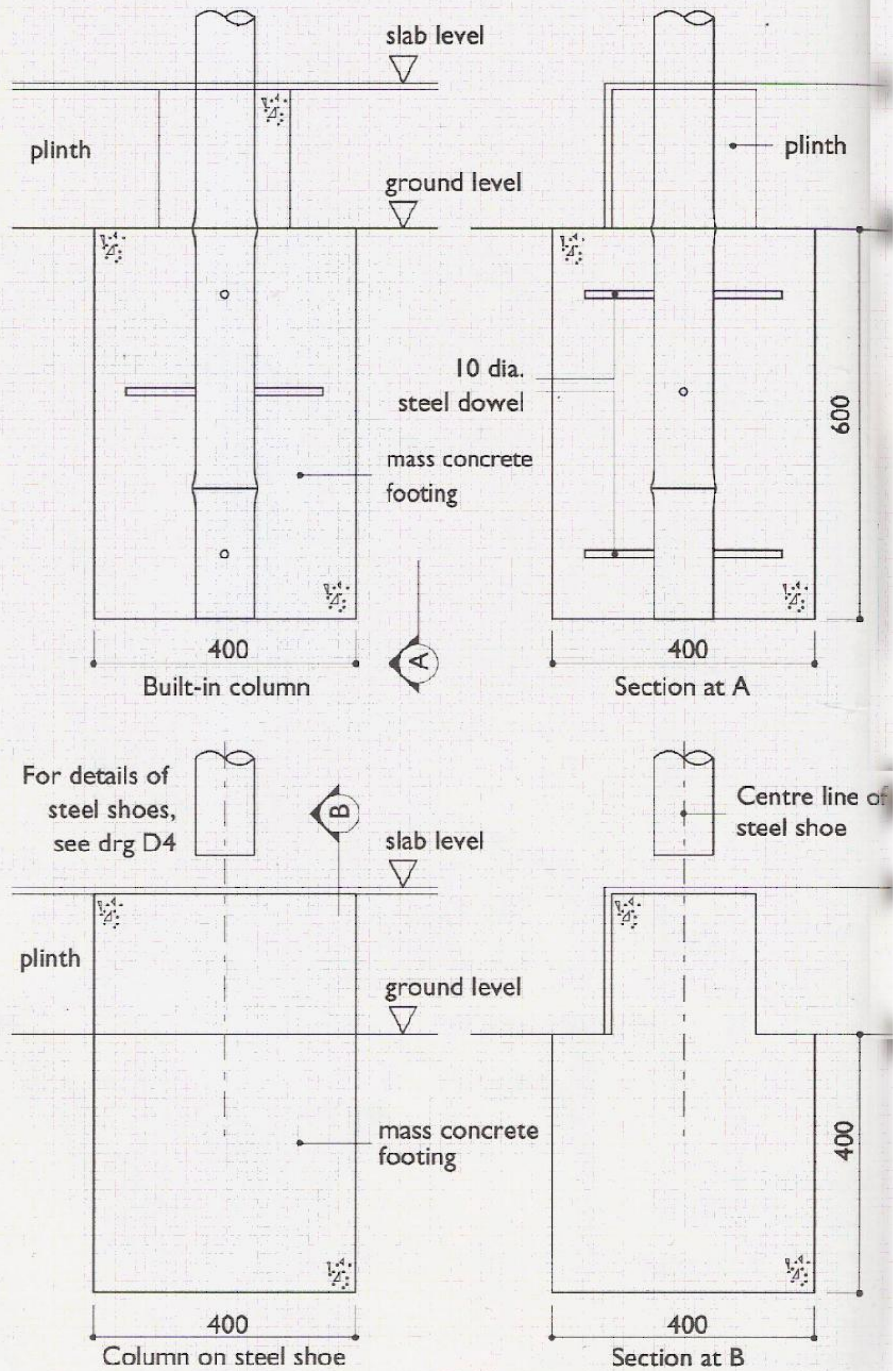


Section BB

Cross-sections
Drawing number C1
Scale 1:50

Notes

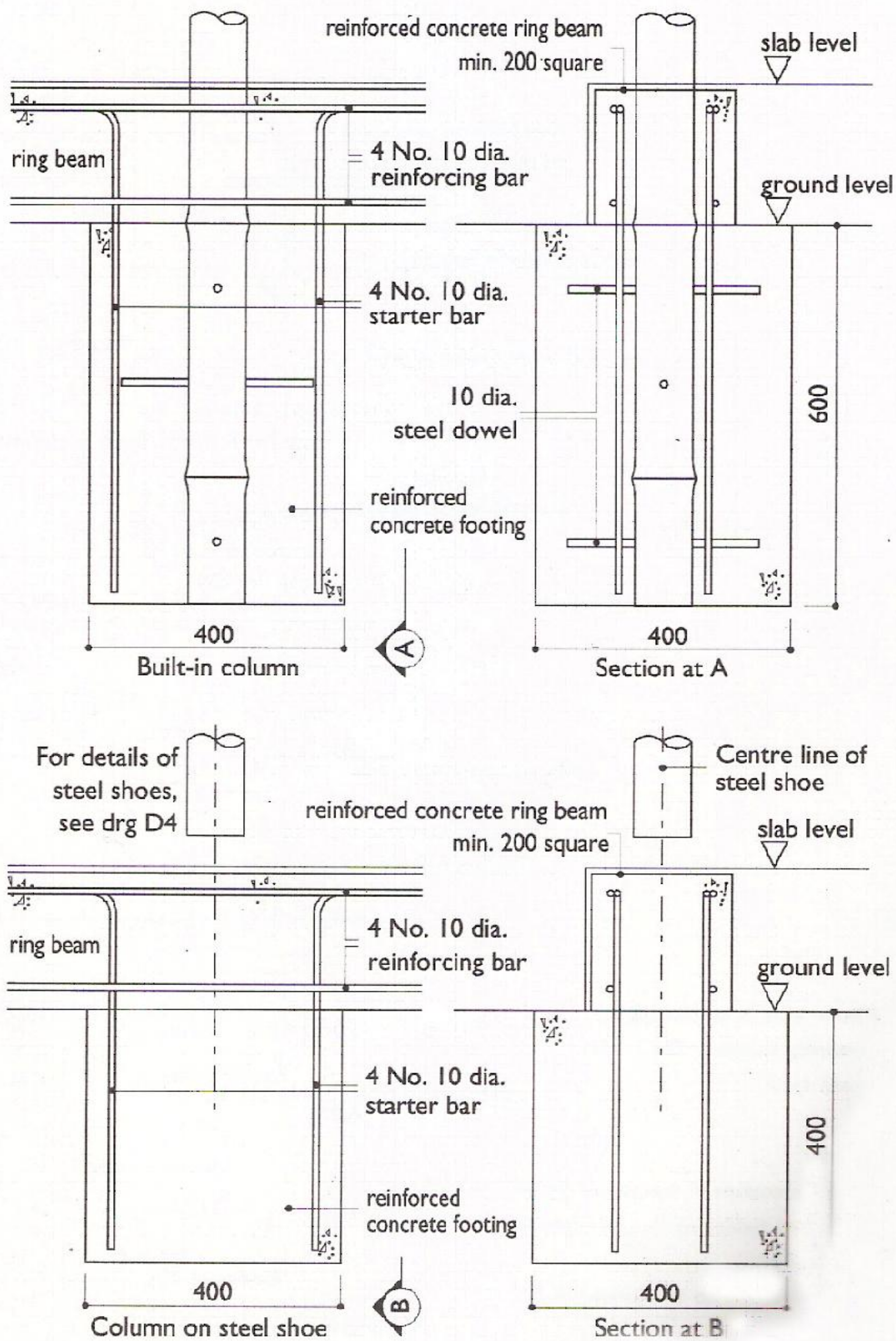
1 All dimensions in mm unless noted



Footing details
Drawing number D1
Scale 1:10

Notes

1 All dimensions in mm unless noted
2 For plinth details, see drawing **D3**



Ring beam details
Drawing number D2
Scale 1:10

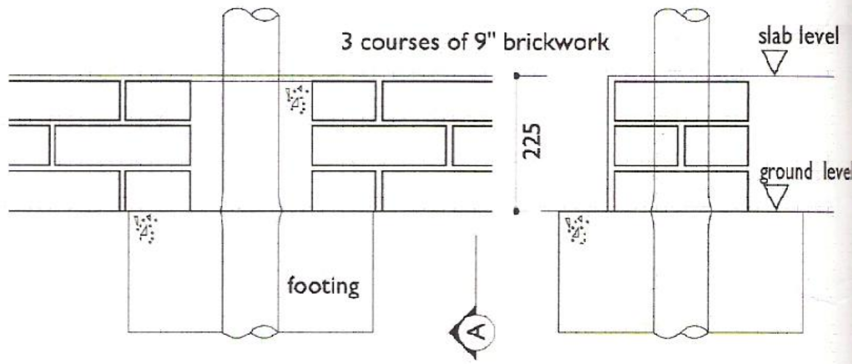
Notes

1 All dimensions in mm unless noted

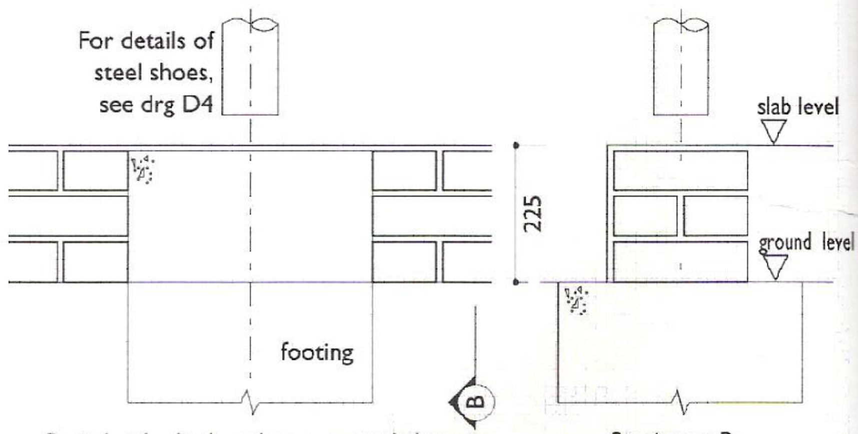
Plinth and floor details
Drawing number D3
Scale 1:10

Notes

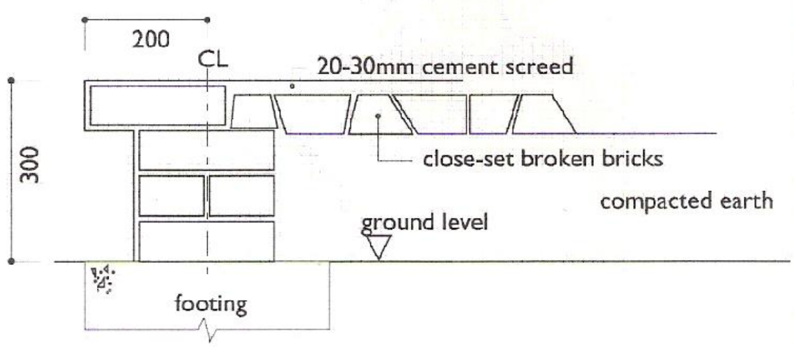
1. All dimensions in mm unless noted
2. Cement render to face of exposed brickwork
3. Concrete blocks or stonework can be used



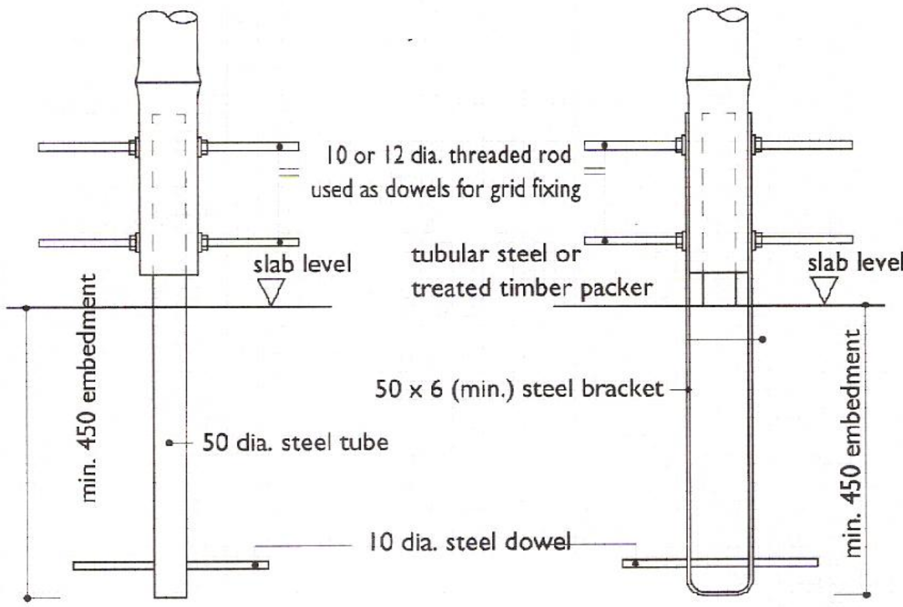
Basic brick plinth, built-in column — Section at A



Basic brick plinth, column on steel shoe — Section at B

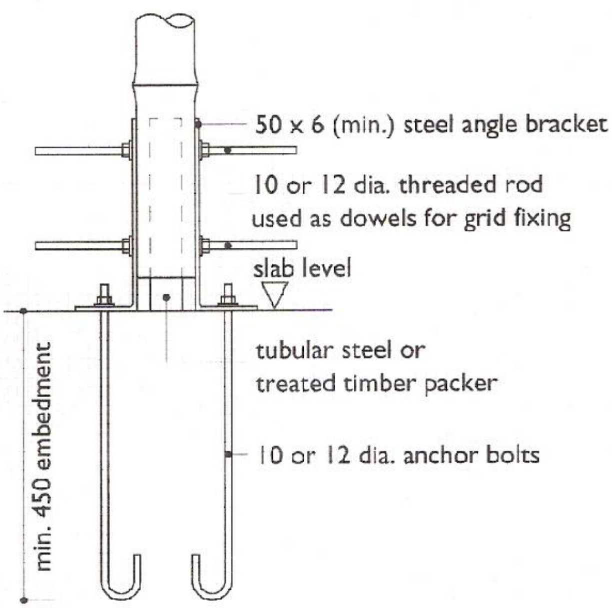


Section through alternative brick plinth with overhang, showing floor construction



Option 1 - Tubular steel shoe

Option 2 - Steel U-bracket

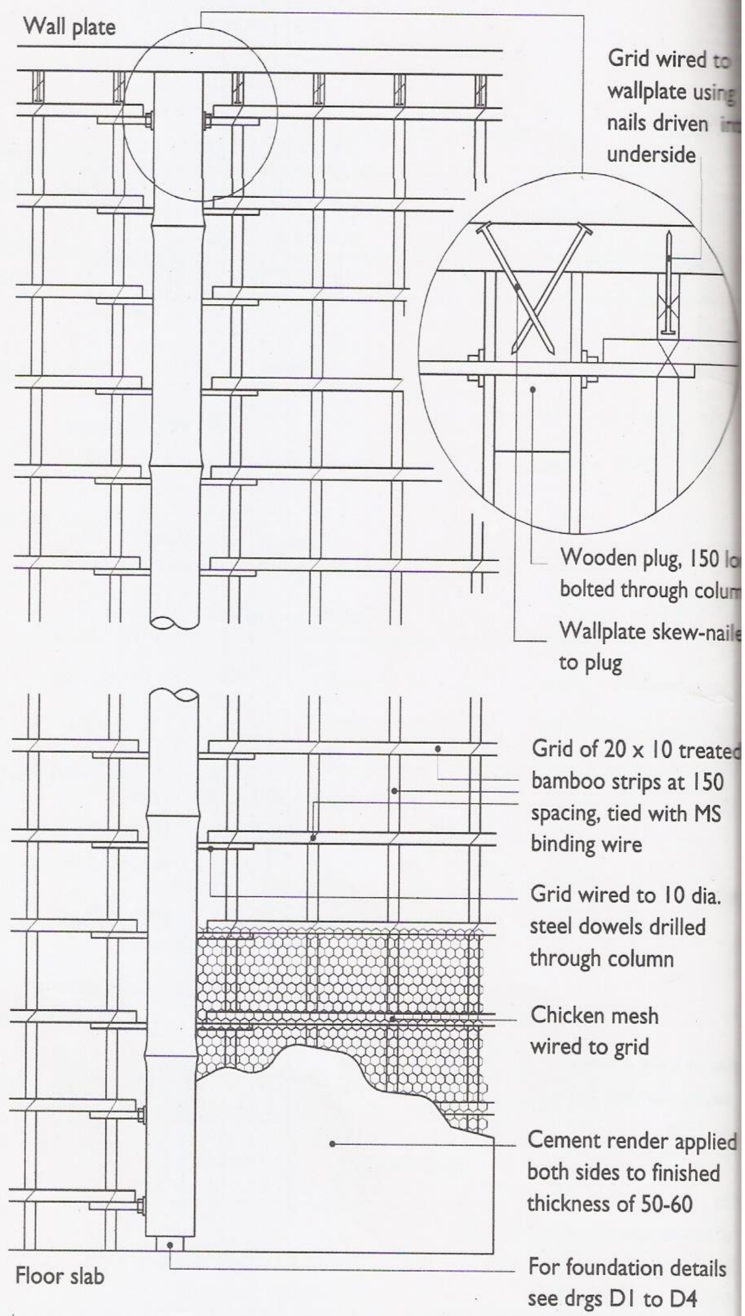


Option 3 - Angle brackets
and anchor bolts

Column base details
Drawing number D4
Scale 1:10

Notes

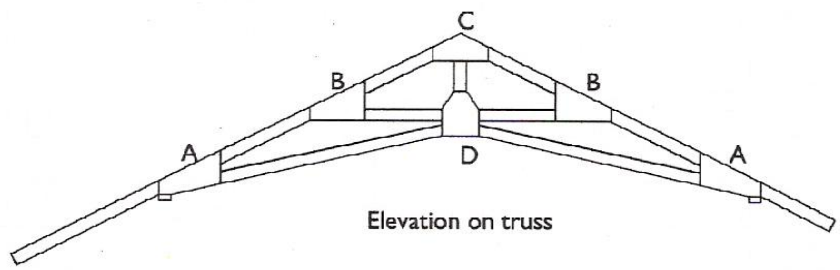
1 All dimensions in mm unless noted
2 To be read in conjunction with drawings **D1**, **D2** and **D3**



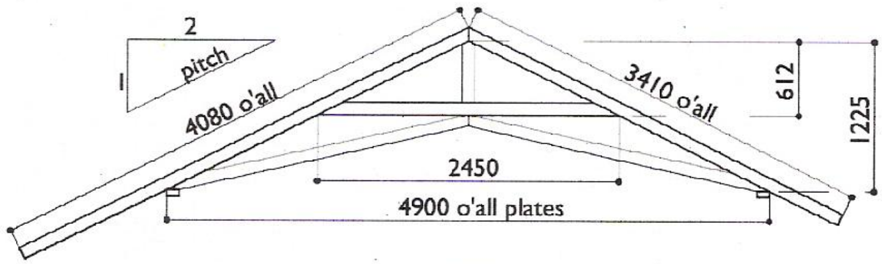
Wall panel construction
Drawing number E1
Scale 1:10, 1:5

Notes

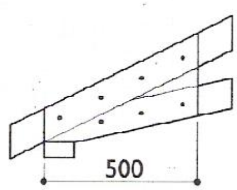
1 All dimensions in mm unless noted
2 To be read in conjunction with drawing **F3**, 'Rafter holding-down details'



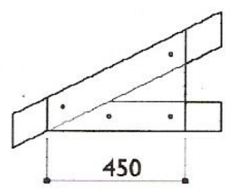
Elevation on truss



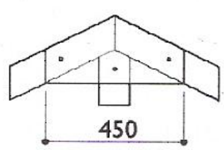
Key dimensions
(other members cut to fit)



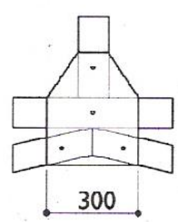
Joint A



Joint B



Joint C



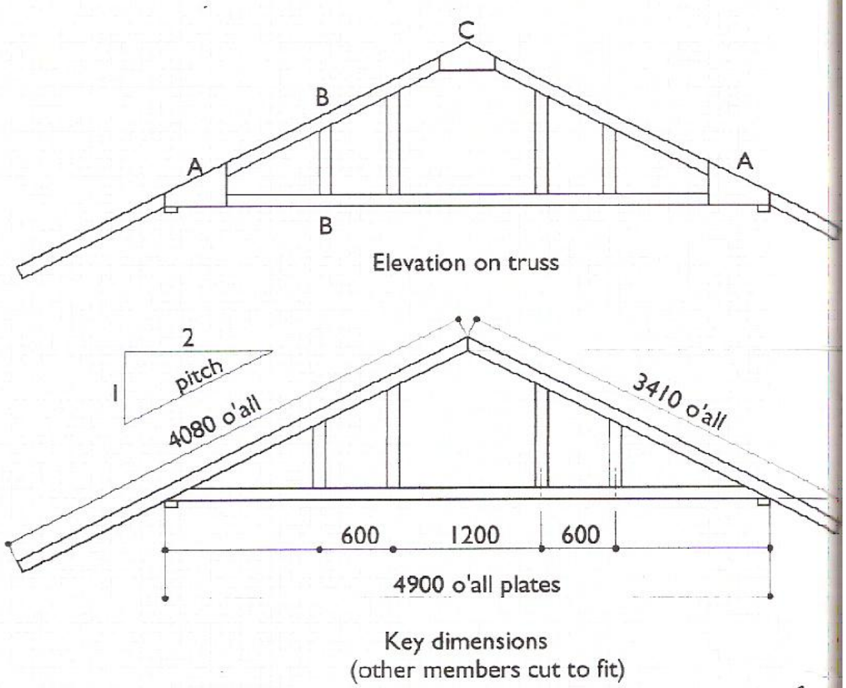
Joint D

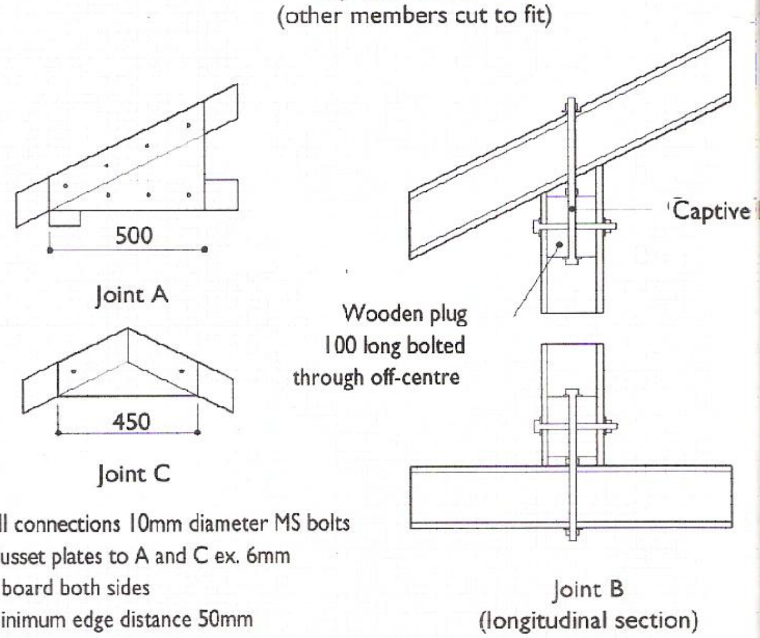
Joint details
Gusset plates ex. 6 mm mat board to both sides
All connections 10 mm diameter MS bolts
Minimum edge distance 50 mm

Roof truss type t1
Drawing number F1
Scale 1:50, 1:20

Notes

1 All dimensions in mm unless noted





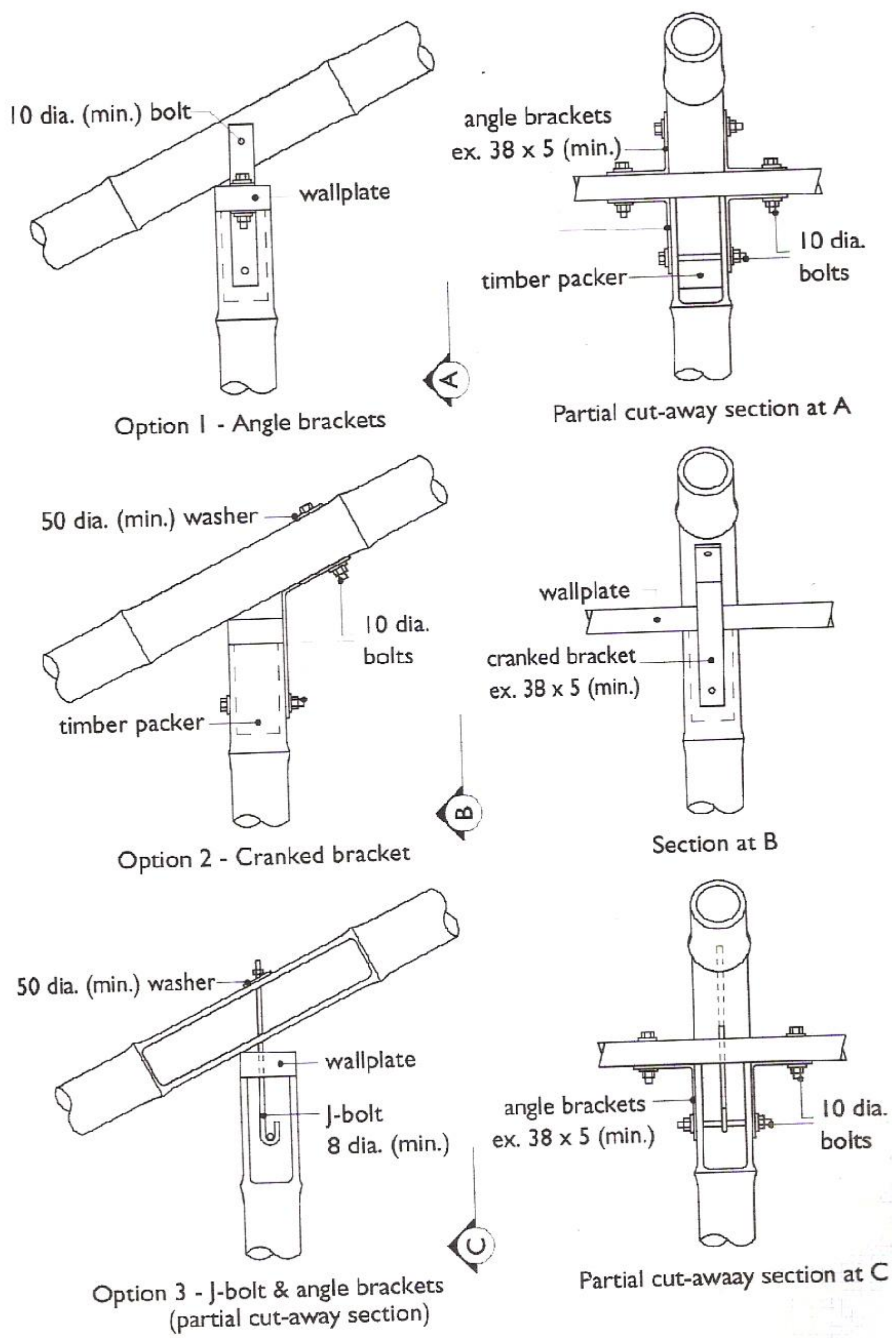
1. All connections 10mm diameter MS bolts
2. Gusset plates to A and C ex. 6mm mat board both sides
3. Minimum edge distance 50mm

Joint details

Roof truss type t2
Drawing number F2
Scale 1:50, 20, 10

Notes

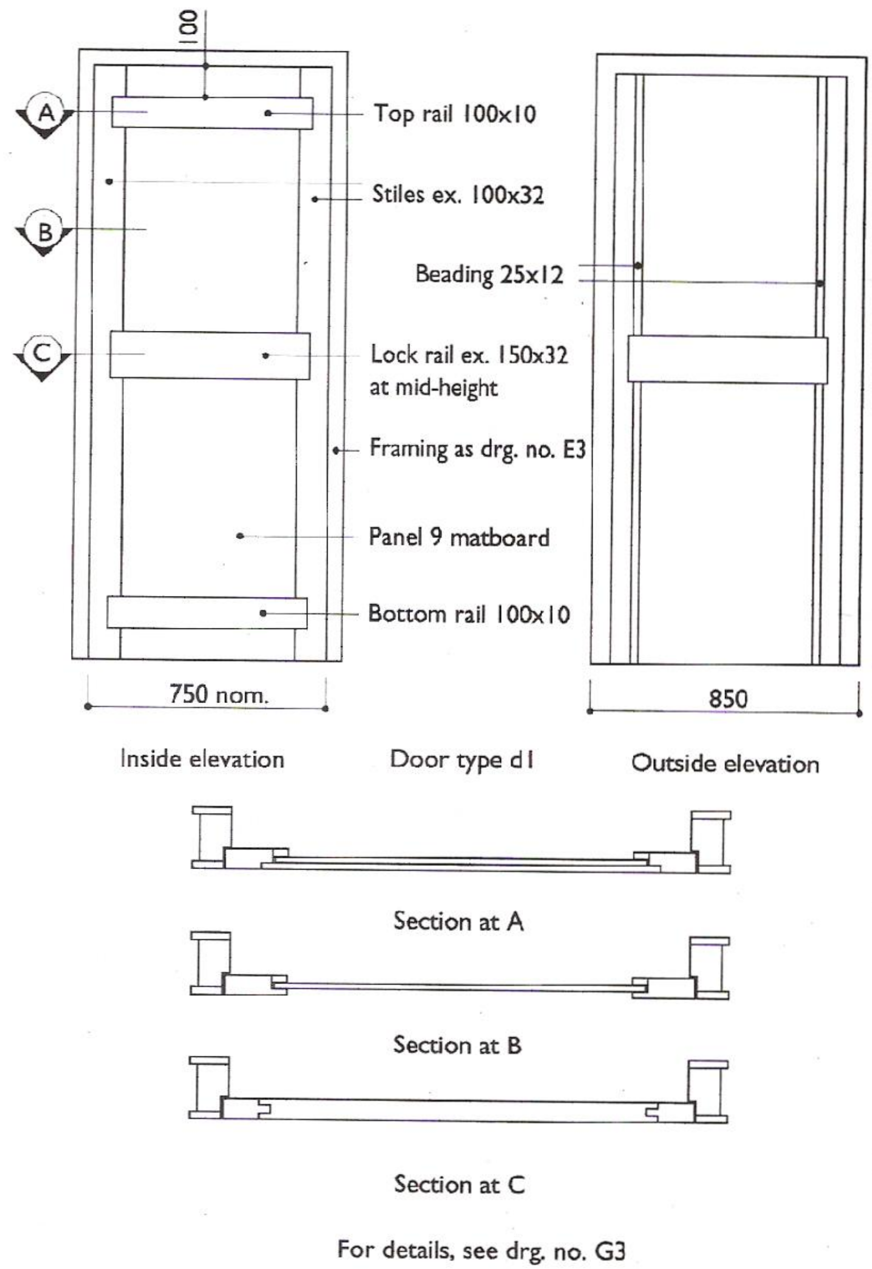
1 All dimensions in mm unless noted



Rafter holding-down details
Drawing number F3 Scale 1:10

Notes

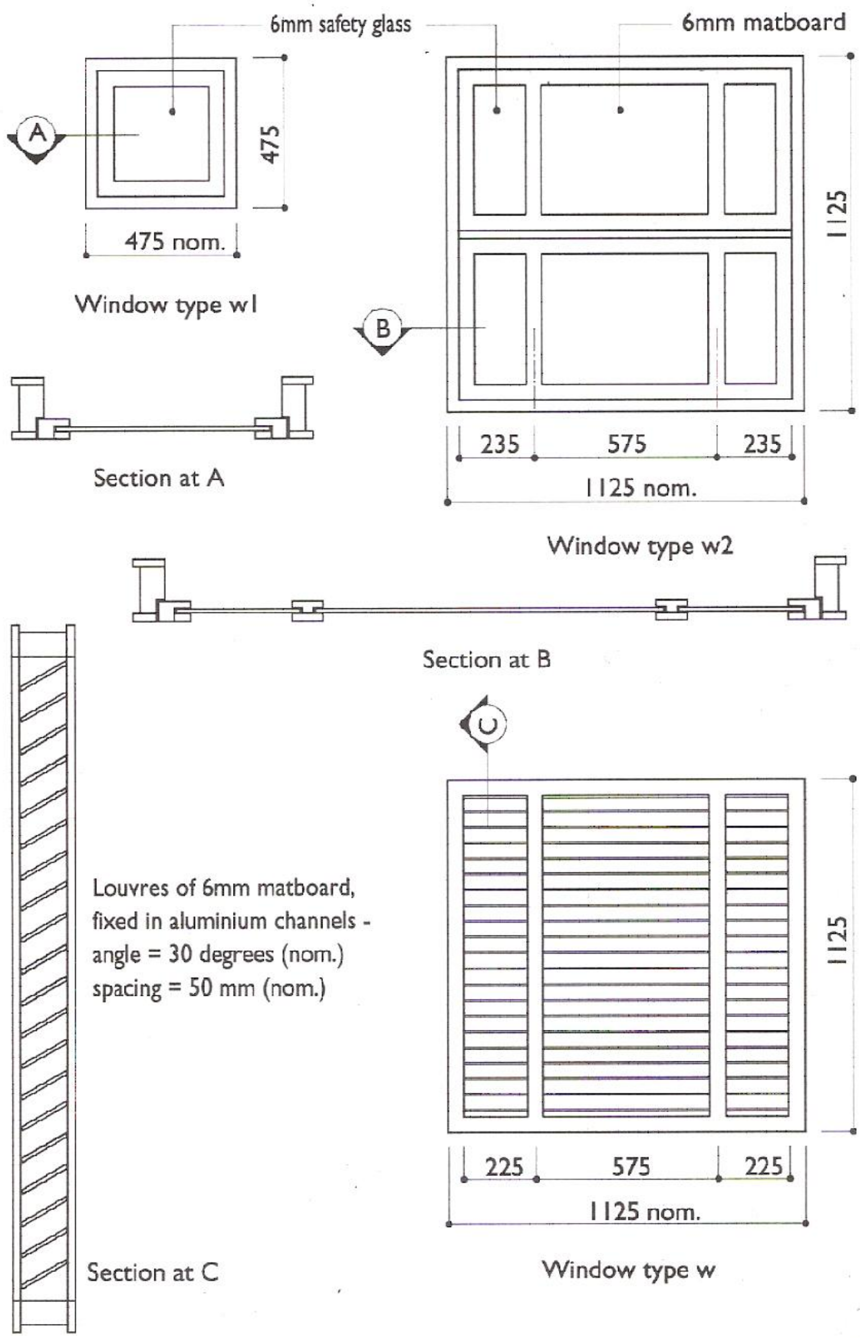
1 All dimensions in mm unless noted



Door construction
Drawing number G1
Scale 1:20, 1:10

Notes

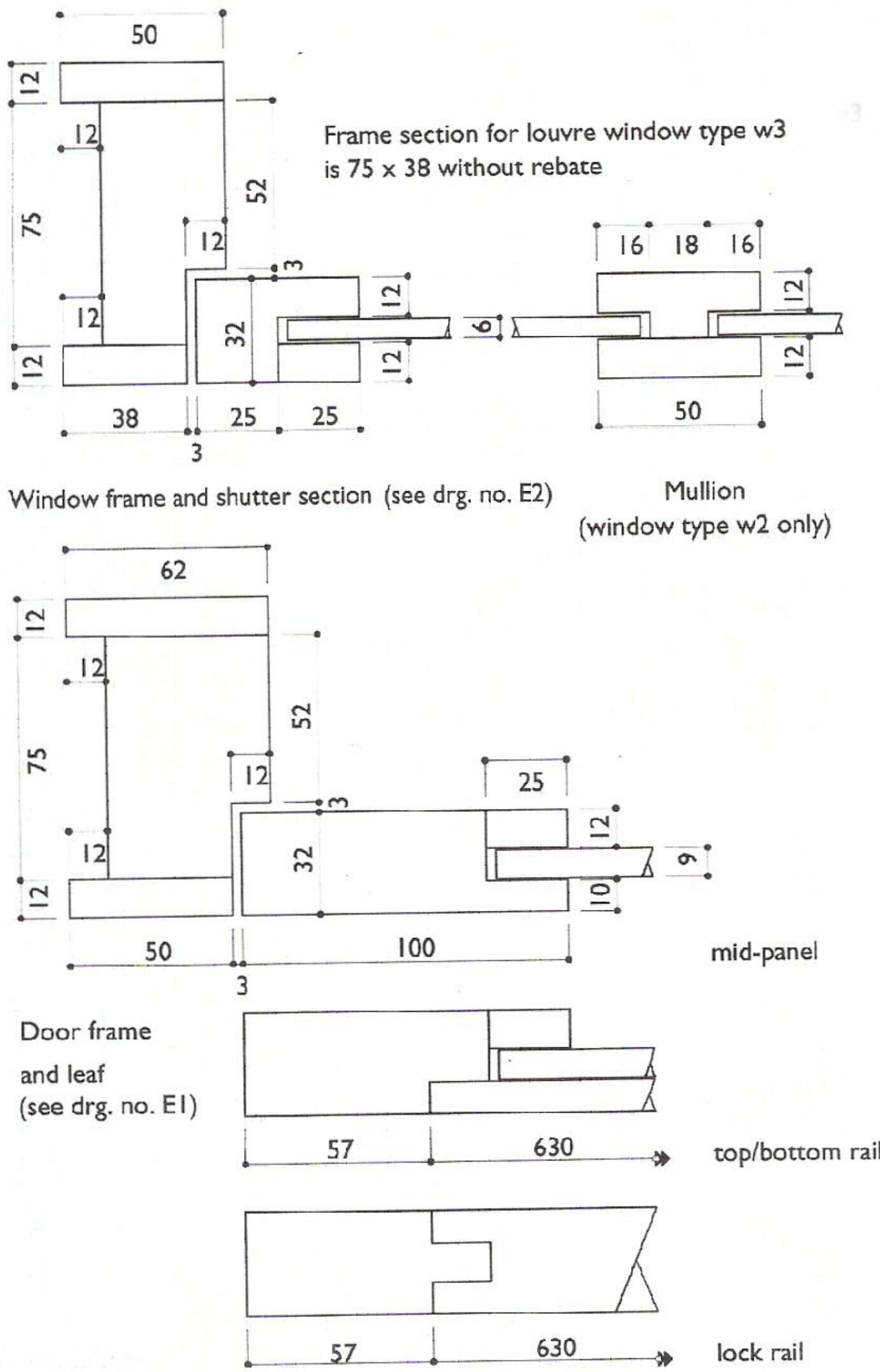
1 All dimensions in mm unless noted



Window construction
Drawing number G2
Scale 1:20, 1:10

Notes

1 All dimensions in mm unless noted
2 For details see drawing **G3**



Window construction
Drawing number G2
Scale 1:20, 1:10

Notes

1 All dimensions in mm unless noted
2 Framing of plantation timber, e.g. silver oak
3 Infill panels of 6 and 9 mm bamboo matboard and 6 mm safety glass

NATIONAL MISSION ON BAMBOO APPLICATIONS
Technology, Information, Forecasting and Assessment Council (TIFAC)
Department of Science & Technology(DST)
Government of India

Vishwakarma Bhawan
Shaheed Jeet Singh Marg, New Delhi 110 016