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INTRODUCTION

Context

Based on the findings presented in Book I, Book II presents guidelines for safer construction in Mumbai’s informal settlements aimed at making the houses both, more climate-resilient and climate-responsive.

Book I presented the various house typologies prevalent in Mumbai’s slums categorized broadly as: Dry, Wet, and Hybrid. It also identified the construction-related problems typically found in these housing types, which are as follows:

- Most houses are made of recycled or second-hand materials—the only affordable option—which are often of poor quality.

- Construction methods are typically lacking in quality and detail. Separate from the affordability issue, two other reasons can be attributed to this: one, the houses need to be put together quickly; and two, there is a knowledge gap in the construction techniques and details which prevents people from exploiting the full potential of the materials.

- Experimentation with new material is rare; colloquial techniques are used which are often of sub-optimal quality.

Book II is structured as a manual that provides guidelines for improving construction of houses in informal settlements. It is designed to be used as a quick reference for house owners and contractors in informal settlements. For the house owners and occupants, it serves as a guide for construction and maintenance of the house; for the contractors, it presents ways to explore new possibilities with existing as well as alternative materials.

Purpose and Audience

This Book does not intend to provide any one specific prescriptive formula for building a house in informal settlements. Rather, it is a guide that does two things: first, help lower income home-builders to make informed decisions on the type of house to build or improve, and how to do it better than most people currently do. The trade-off between the higher upfront cost of methods recommended here in relation to the benefits achieved in the longer run is clear: a safer and more durable house at a marginally higher—yet very affordable—cost, that extends the same materials closer to their optimal potential, and requires the same labor/skill set that is currently available. To this effect, this Study makes a compelling case.

Second, it is hoped this Book, or possibly even the methodology used for the underlying research, will serve as a resource for (i) government, donors, and policy-makers by presenting a relatively cheaper and sustainable approach to slum improvement and disaster risk reduction, (ii) NGOs and microfinance agencies, as a guide on what sorts of ‘improvements’ to promote or finance, and to inform the development of construction-related technical assistance/training programs for residents of informal housing.
While the applicability of this research and the findings extend beyond Mumbai to other large developing country cities where flooding is a problem, the underlying methodology for this research is one that can be adapted to slum settlement anywhere, particularly in light of the increasing disaster-related risks facing poor people across the globe.

Contents and Structure

Book II constitutes four parts:

Part 1 addresses issues related to prevalent construction materials by providing recommendations on their selection, usage, and maintenance, so as to avoid repetitive and costly repairs.

Part 2 addresses issues related to the assembly of these materials in house construction—for example, the assemblies for foundations, plinths, floors, walls, and roofs—and suggests simple and cost-effective improvements to existing methods. (Note: Reinforced Cement Concrete (RCC) construction is not included in this report as this requires some level of professional engineering, and as such is not seen as the recommended mode of construction for self-built informal housing.)

Possibilities of making the houses more climate-responsive through improved ventilation, lighting, and sanitation are also discussed.

Part 3 assimilates the recommendations in Part 2 into “ideal” prototypes for each housing typology: Dry, Wet, and Hybrid, with specifications and costs for ‘existing’ and ‘recommended’ construction methods for each.

Part 4 draws from outside experiences and presents new low-cost construction materials and methods to be explored by house owners and contractors as innovative alternatives to current practices.
PART 1
IMPROVING MATERIAL USAGE

1.1 Structural Timber
1.2 Steel
1.3 GI Corrugated Sheets
1.4 Brick
1.5 Plywood
1.6 Plastic/ Vinyl Sheets
1.1 STRUCTURAL TIMBER

**Selection**

As good quality wood (old and new) is extremely expensive, poor quality wood is used, which is susceptible to rotting in Mumbai’s humid climate. Moreover, this poor quality second-hand wood is likely to have rot and nail holes in it, which makes it more prone to termite attacks and may already be infested with termites.

1. While choosing timber, care should be taken to ensure that it is free of rot, cracks, bends, excessive nail holes and infestation (see A).

2. A coat of Black Japan should be used whenever members are in contact with moisture – e.g. when embedded into foundation footings or masonry walls (see B and C).

3. Spanning sections should be used vertically (see D).

4. Joints between horizontal & vertical members should be secured with cleats (see E).

**Usage**

**Maintenance**

1. The house occupants should be watchful for signs of wood damage.

2. Wood with infestation, rot, bends should be removed, and any visible cracks stitched.
Selection of Materials and Details

While choosing wood, house owners should ensure that wood is free of rots, cracks, bends, excessive holes, and infestation.

Embedding wood in foundation pedestal.

Embedding wood in wall.

Spanning sections should be used vertically.

Joints between horizontal and vertical sections should be secured with cleats.
1.2 STRUCTURAL STEEL

Selection

Use of steel structural members is relatively new. With no inherited knowledge, its use is not optimal and joineries are of poor quality. The following points serve as a guide in the selection of material -

1. Ensure that the steel is not corroded/rusted.

2. Various types of steel sections are available in the market (see A). The following guidelines should be referred to when procuring steel sections –
   i. Box sections may be used as columns;
   ii. Channel and I sections may be used as columns and beams;
   iii. Angle and T sections may be used as purlins and joists;
   iv. Pipe sections may be used as purlins.

Usage

1. Avoid embedding steel into the ground; instead a pedestal should be built, over which a base plate could be fixed to attach vertical members. When steel members need to be embedded into masonry walls, the part that gets embedded should be coated with Black Japan (see B).

2. Use all spanning members in vertical sections (see C).

3. Welds are faster and cheaper than bolts and rivets. There is also an availability of skill amongst local contractors for welding (see D).

4. Steel if used as portals braced with horizontal members between portals, can provide a very stable and strong structure, capable of carrying heavy load.

Maintenance

1. Be watchful for rust and immediately remedy such occurrences by scrubbing off the rust and applying a coat of paint over the steel.

2. Scrub off any minor surface corrosions before use. Coat all steel members with red-oxide. A coat of oil paint will further enhance the life of the steel.
Selection of Materials and Details

A Choice of steel section for use as structural members.

B Embedding steel should be avoided. If necessary, the embedded portion should be used coated with Black Japan/other waterproof compound.

D Welds are faster, easier and cheaper to install than rivets.

C Steel sections should be installed vertically for structural purposes.

E Steel members used as portals with horizontal braces provide a stable and strong structure.
### 1.3 STRUCTURAL BRICK

#### Selection

The skills and labor for brick laying is adequate. However, the quality of the brick, and its maintenance is clearly a problem in the informal settlements.

1. Select bricks that are hard, uniform in color and free from holes or cracks.

2. Ensure that sand used for the mortar is free of clay, organic matter and salts.

3. This can be done by rubbing the sand against the fingers: it will stick to the hand if it contains clay or organic matter. Another way to test the purity is to keep a small portion of sand in a transparent jar with water for some time. The clay layer will be distinctly formed if present. The water can be tasted to identify the presence of salt.

4. Second hand bricks are best used for coba (brick bats). However, if second hand bricks are the only alternative for walls, then care should be taken that they are complete and unbroken. If broken bricks are used, then care should be taken that there are no continuous vertical joints. Walls made of secondhand or broken bricks must be plastered externally.

#### Usage

1. Soak the bricks in water for at least two hours before use. The mortar used for laying of bricks should be 1 part cement and 4 to 6 parts sand.

2. External walls should be at least 4.5” thick (i.e the width of the brick). For a two story building, the lower floor should be at least 9” thick (i.e the length of a brick) and the upper floor 4.5” thick. Brick walls with piers could be laid in a manner that they double up as internal niches (see A and B). This provides space for storage and furniture within the house. Two or three iron bars/concrete pads could be laid after every meter of the masonry along the length of the wall to ensure stability (see C).

3. To avoid wall seepage, it is critical to plaster external walls or, at minimum, to cover the external surface with plastic / vinyl sheets during monsoons (see D). Sharing common external walls instead of building two walls next to each other is not only economical, but also an efficient way to manage space and avoid water seepage.

4. Window opening should not be more than 60 cm and a thick kuddapa stone could be used as a lintel for door and window openings. Corbelled openings are generally cost effective (see E). However such openings should be small and an iron mesh covering from inside would protect the house.

#### Maintenance

1. Do not ignore critical signs like vertical deep cracks, sinking, tilting, etc. Take immediate measures to identify the cause and remedy it.

2. Fungus/ mold may be observed on the internal surfaces during monsoons. This is due to water seepage. Removal of fungus by scrubbing and application of borax powder (carom board powder) dissolved in water is effective against such fungus mold.
Selection of Materials and Details

**A** Brick wall with piers at regular intervals of 1.2 to 1.5m.

**B** Internal niches of a brick wall with piers may be used to integrate furniture.

**C** Concrete pads with nominal reinforcement at 1m intervals to strengthen the brick wall.

**D** Plastic sheet can be used as a cladding materials where plastering is not possible.

**E** Corbelled openings with protective iron mesh.

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1.4 GALVANIZED AND CORRUGATED SHEET

Selection

Galvanized Iron (GI) corrugated sheets serve as an effective cladding material for walls and roofs, but are susceptible to corrosion. Moreover, joineries are often of poor quality, resulting in water leakage, which adversely affects members.

1. Ensure that the GI sheet is not rusted, and that the coating of galvanization is intact.
2. Thicker gauge sheets are preferred since they are less likely to crack during drilling.

Usage

1. Corrugations should always be vertical when GI sheets are used for wall cladding (see A), such that water drains away quickly from the surface.
2. Overlaps between adjoining GI sheets are important to prevent water seepage (see B).
3. GI sheets should always be bolted at the crests and never at the troughs. While fixing the bolts, rubber washers should be used which will make the joints effective against water (see C, D and E).
4. Corners where two sheets meet are prone to water seepage. These can be secured by folding the sheet over the other. When such folding is not possible (over a ridge of a double-pitched roof, for example) a ridge piece should be used. Depending on the situation, other accessories like the corner piece, flashing board, etc. can be effectively used for waterproofing (see F).

Maintenance

1. House occupants should be watchful for signs of rusting.
2. Where rusting is observed immediately remedy that by scrubbing off the rust and applying a coat of paint over the sheet.
3. If the damage is severe, the sheet should be replaced.
Selection of Materials and Details

A. Corrugations should always be vertical when GI sheets are used for wall cladding.

B. Detail showing overlap of GI sheets and location of J-bolts.

C. Detail showing method by which a J-bolt should be used to attach the GI sheet to the steel member.

D. Detail showing the joinery of GI sheets (at the crest) to the steel member using bolts.

E. GI Sheets should always be bolted at the crest and not at the trough.

F. Accessories (shown above) can be used to resolve corners and joints.
## 1.5 PLYWOOD

### Selection

Second-hand plywood panels are generally used as cladding for walls and floors. In most cases, these panels have previously been used as shuttering for concrete and is generally thick and coated with red oxide. This is useful when plywood is reused.

1. Ensure that the plywood does not have cracks, bends, excessive nail holes, cracked/chipped edges and it is not infested with termites (see A).

2. Second-hand plywood may also come in varying sizes. Smaller pieces are cheaper, but the trade-off is that they create more joints and are difficult from a construction perspective.

### Usage

1. Avoid using plywood as external cladding as it is susceptible to rotting from dampness or water.

2. If it must be used, then it should be coated with red-oxide, and during monsoons it could also be secured with plastic covering (see B).

3. Edging of plywood with Black Japan is also a good practice that prevents water from seeping in to the plywood.

4. Never use plywood as a structural member (see C).

### Maintenance

1. Be watchful for signs of termite infestation, bends and cracks in plywood.

2. Immediately remove and replace pieces with infestation, rot, or bends, and stitch any visible cracks.
Selection of Materials and Details

Typical deterioration that can occur in recycled plywood sheets.

A

Plastic over plywood during monsoon.

B

Plywood should not be used as structural members.

C

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Part 1: Improving Material Usage
1.6 PLASTIC/ VINYL SHEETS & TARPALIN

**Selection**

These are often used temporarily during the monsoons to protect against water.

1. Cheap vinyl sheets used in hoardings are easily available, and are cost-effective.

2. Ensure that the sheet has no holes and that it does not crack when bent.

3. The material should be thick enough to withstand the weather.

**Usage**

1. Sheets can be used as an effective solution for walls that are inaccessible, where plastering is difficult (see A).

2. Covering the walls and/or roof with plastic/vinyl sheets and tarpaulin is a temporary quick-fix waterproofing measure during the monsoon. If properly used, these offer cheap and effective protection from the rain. However, the fixing details for these have not been well developed and often these are secured just by placing stones over them, or with nails. These stones often get dislodged by the wind and damage the GI sheets; the nails make holes that compromise the sheets (see B).

3. If plastic sheets are used to cover a roof, ensure that the sheet covers the entire roof, and the corners and edges are secured properly (see C).

4. If using nails to secure the sheets, use a wooden pad or folded plastic piece to avoid tearing (see D).

5. When joining two sheets, use rubber solution as the adhesive, and ensure adequate overlap. They can then be secured with ropes such that they form a jacket over the roof or wall (see E).

**Maintenance**

1. Remove sheets after every monsoon; if they are left installed for extended periods of time, they will collect dirt causing pest infestation. Ensure that the sheets are stored away from fire hazards.

2. Take care to avoid rips or scratches in the sheets from rodents or animals. In case of a tear, the sheet should be mended with rubber solution.
**Selection of Materials and Details**

A. Plastic sheet can be used as a cladding material where plastering is not possible.

B. Do not use brick, stone or nails to keep plastic sheets in place.

C. Ensure that plastic sheets cover the entire roof and that edges and corners are fastened securely.

D. Method for fixing plastic sheet to a timber member.

E. Recommended method for joining two sheets.

Plastic sheet can be used as a cladding material where plastering is not possible. Do not use brick, stone or nails to keep plastic sheets in place. Ensure that plastic sheets cover the entire roof and that edges and corners are fastened securely. Recommended method for joining two sheets.
PART 2
IMPROVING EXISTING METHODS

2.1 Foundation and Plinths
2.2 Wall Assembly
2.3 Floor Assembly
2.4 Roof Assembly
2.5 Thermal Comfort
2.6 Space Utilization
2.7 Maintenance
2.8 Costs
2.9 Cost and Benefit
2.10 Materials, Procurement and Methods of Construction
2.1 FOUNDATION & PLINTH

Typical Problems

1. Foundations are not made sufficiently deep and often there is no footing to walls or posts. This causes differential sinking which affects other structural members and compromises the overall stability of the house. Often no soil and edge stabilization is done, leading to conditions of perpetual settlement.

2. There is typically no plinth, and/or the floor level is below external ground level causing water to enter the house.

3. Water seepage from the ground into the floor and walls makes the house damp.

Recommendations

Foundation: Use pedestal posts to embed columns rather than anchoring the steel columns or wooden posts directly into the ground (see A).

1. Ram the earth and place rubble packing below the footing to protect against sinking or settling of wall. Alternately, build gravel piles beneath the plinth. Construct brick walls to connect pedestals; this will serve as plinth protection (see A,B).

2. Start the wall or pedestal at least 45cm below ground level for single storied houses, and 75cm for double storied structures. This will act as a foundation. A 10cm thick footing below the wall and post needs to spread at least 10cm beyond the wall and the post edges. This will be effective against differential sinking (see A,B).

3. Use plastic between layers of brick/concrete blocks and between rammed earth and dry rubble. This is an effective water proofing technique that prevents ground water seepage. Waste plastics from hoardings have sufficient thickness for the purpose (see C).

Plinth: Ensure that the plinth is at a level higher than the highest external level in the adjoining area.

1. The plinth should be made of rammed earth and rubble packing finished with plain cement concrete.

2. Build an apron paving either in plain cement concrete or any other material to protect the plinth from water and pests.

Stilts: Bamboo can be used very effectively for stilts, as an alternative to a high plinth (see D).
Suggested Fixing Details

A Typical foundation details with pedestals

B Ensure that the internal plinth is above the external ground line.

C Recommended plinth configuration: include recycled plastic sheet for to guard against water seepage from the ground through capillary action.

D Bamboo stilt house
2.2 WALLS

Typical Problems

1. Exposure of walls to moisture from the ground, particularly during monsoons, causes dampness in unplastered brick, corrosion in steel and rotting in wood.

2. Improper joineries in structural members result in a weak structure, which requires regular repairs and maintenance.

3. Brick walls that are not plastered from the outside are prone to water seepage.

4. Improper laying & joineries in cladding members (like GI sheets & plywood) at overlaps & corners result in leaks and seepage.

Recommendations

1. Use a coat of Black Japan on structural members wherever they come in contact with the ground or with wet construction.

2. Anchor the steel and wooden structural members: a 300mm anchoring into a pedestal for wood and in case of steel, a base-plate over the pedestal is required.

3. Vertical structural members should be full length for at least one storey.

4. The vertical structural members used in the ground level of a two storied structure should be at least 10cm x 10cm for wood and 5cm x 7.5cm in case of steel (I or C Sections). At the upper floor, the sections can be 7.5cm X 7cm for wood and 5cm X 7.5cm in case of steel.

5. The spacing between two such members should be 1.2 m. These members should be tied by horizontal short struts/long ties (3.75cm X 5cm wooden sections or 3.75cm X 3.75cm angles in case of steel). Use of cleats to support struts is recommended. At the top level, the vertical structural members should be tied with a long continuous member on the edge or a ring beam.

6. GI sheets used for cladding should always be aligned so that corrugations are vertical, with an overlap of at least 10cm. Vertical joints should ensure that water drips out of the house. They should be fixed with rust proof J- bolts and the external surfaces should be carefully sealed with rubber washers and finished with M-Seal. Vertically aligned corrugations also enhance the vertical and lateral load carrying capacities of the steel frame against both gravitation and lateral load.

7. Old plywood sheets used as walls should be overlap and not fixed as butt-joints. This should be done in a manner that water drips outside.

8. Corners should be secured by folding the GI sheet on one side over the other side and then fixing it with an adequately overlapping corner piece.

9. Use a brick wall at least one brick thick on the lower level and half brick thick on the upper level. Horizontal reinforcing ties after every one meter height will make the walls stronger. Plaster and paint both sides of the wall (should funds be scarce all the external faces of brick walls must be plastered). If plaster is not possible on the external surface, a plastic sheet or tarpaulin sheet should be stretched over such surface during monsoons.
Suggested Fixing Details

A  Spacing of structural members – wood, steel and brick

B  Use of ring beams and base plates in wood, steel and brick construction.

C  Method for fixing J-bolts for wooden and steel members

D  Secure corners by folding sheets or use a corner/angle piece.
2.3 FLOOR ASSEMBLY

Typical Problems

1. Lack of waterproofing causes seepage from the ground, particularly during the monsoon.

2. Beams (part of the floor structure) are oriented with the longer side of the rectangular cross-section facing down, which causes sagging and weakening of the structure.

3. Joineries are of poor quality, that compromise the strength of the structure.

4. Joints between vertical and horizontal members on the exterior are prone to water seepage.

Recommendations

1. Coat all structural members (steel, wood) with Black Japan wherever they come in contact with ground or with wet construction. All structural members should be coated with red-oxide before use; a coat of paint is recommended after installation.

2. All spanning members should be used in vertical sections. Use of cleats / capitals is advisable to support them. As far as possible, joists should sit over vertical members. Where this is not possible, they should sit on a ring beam spanning across structural members.

Wood floor

1. Block-board is preferable over plywood. If plywood is used, it should be at least 25mm thick.

2. The floor boards are to be supported over joists that are not more than 0.6m apart from each other, and spanning no more than 1.2m (see A).

3. Wood joists: The joist size for a span of 1.2m should be 3.75cm x 5cm. The joists should then sit on beams spanning the shorter dimension of the room, aligned exactly over the vertical structural members. A beam spanning 3m should be at least 7.5cm x 15cm (see A, C).

Steel joists: Steel joists for a span of 1.2m should be 3.75cm x 3.75cm angles. The joists should then sit on beams that span the shorter dimension of the room. These should sit exactly over the vertical structural members. A steel beam spanning 3m should be at least 5cm x 7.5cm (see B, D).

Stone/tile floor (see E)

1. Stone flooring can only be used when the vertical structure is in brick or steel.

2. Anchor the steel beams (with Black Japan treatment) into the brick wall or weld them to the steel vertical members. The beams should be I, C or box sections of size 7.5cm x 12.5cm, spanning a distance of 3m, and should be placed at a distance of 1.2m.

3. Attach the joists (I or inverted T sections) of dimensions 5cm x 10cm to these beams; ensure that the distance between two joists is not more than 60cm.

4. Minimum 3.75cm thick kota or 5cm thick kuddapa should be placed on these joists. These surfaces should be then covered with a coba of 5cm before finishing the surface with another thinner stone or tile. Ensure that none of the steel members are exposed to rain water.
Suggested Fixing Details

A Spacing of structural members in wood

B Spacing of structural members in steel

C Detail of wood floor with wood joists, beams and columns

D Detail of wood floor with steel joists, beams and columns

E Stone floor detail with steel structural members.

2.4 ROOF ASSEMBLY

Typical Problems

1. Poor quality assembly of roof cladding material causes water leakage from the roof.

2. Roof leaks are temporarily remedied by placing tarpaulin or plastic sheets secured loosely by weights or with nails. Nails rip the sheets.

3. Creases in the plastic sheets causes water logging and further seepage.

Recommendations

1. Care should be taken to ensure that all structural members in steel or wood are coated with red oxide and painted.

2. The roofs should extend at least 45cm beyond the house and should have a slope of at least 30cm over 4m span (see A).

3. Lay the GI sheets on joists running across the shorter length of the house. These joists should span over structural verticals or brick walls (with Black Japan Treatment). The joists could be: 7.5cm x 10cm in wood; 7.5cm diameter circular section; or 5cm x 8.75cm steel section. The distance between the joists should be around 1.2m, not exceeding 1.4m (see B).

4. Secure the junction of GI roofs and adjoining walls with a coat of plaster (see C).

5. Secure the junction of GI sheet overhangs and brick walls with a coat of plaster (see D).

6. Overlap of sheets should be at least 10cm.

7. A plastic sheet cover is generally used over roofs that leak. Instead of simply using stones to hold these down, a detail where the plastic jackets over the entire roof could be used (see E,F).
Suggested Fixing Details

A. Recommended overhangs and slope.

B. Recommended spacing of joists for roofs.

C. Junction of GI roofs and adjoining walls

D. Junction of GI sheet overhangs (chajja) and brick walls.

E. Do not use brick, stone or nails to keep plastic sheets in place.

F. Ensure that plastic sheets cover the entire roof and that edges and corners are fastened securely.
2.5 THERMAL COMFORT

Typical Problems

Little or no attention is given to light and ventilation in most houses. Windows are typically very small, and covered with either plywood or plastic shutters/curtains which offer little protection from rain water.

Excessive heat is caused indoors by metal sheets on the roofs and walls, with little or no ventilation. This is particularly bad in the monsoon, when many houses get ‘wrapped’ in plastic sheets to protect the inside from leaks – as a result, even if windows exist, they serve no purpose.

Recommendations

Natural Light:
1. A small part of the roof can be made in transparent corrugated sheet, which will help get natural light into the house (see A).
2. Though CFL bulbs have a relatively high initial cost, they are useful for two reasons – first they use much less electricity and second, they emit much lesser heat than incandescent lights.

Heat Reduction:
1. Fixing a thin second-hand plywood on the internal side of the GI wall with waste polystyrene in between will be effective against the heat gain in GI Sheets (see C).
2. Another layer of ceiling below the roof attached to the same structural system will reduce the heat gain substantially (see D).

Ventilation:
1. A number of accessories from TATA SHAKTEE & RAMCO can be innovatively and effectively used on the roof and GI walls to improve lighting & ventilation conditions in the house.
2. A gap could be left between the roof and the walls. This could be secured by steel mesh or grill. This will ensure that hot air moves outside the house. The space below the roof will remain ventilated decreasing heat gain in the house (see E).
3. In GI walls, openings could be kept between structural members and innovative details could be worked against water using accessories like ridge piece, flashing board & louvers etc. (see F).
4. In brick walls, ventilators & windows can be made using corbelling techniques along with a steel mesh. Brick jali walls can be built to augment ventilation in the house. These can be above eye level wherever there are privacy issues. These will also help in bringing in natural light into the house (see G).
Suggested Fixing Detail

A. TRANSPARENT SHEET FOR LIGHTING

B. VENTILATOR OVER ROOF

C. IMPROVING HEAT RESISTANCE IN GI WALLS

D. IMPROVING HEAT RESISTANCE IN GI ROOFS

E. ABOVE: SECTION, VIEW OF VENTILATOR GAP BETWEEN WALL AND ROOF

F. BELOW: VIEWS OF RAIN SCREEN AND WINDOW

G. ABOVE: SMALL CORBELLED OPENNINGS WITH MESH FOR PROTECTION, SMALL CORBELLED OPENNINGS
2.6 SPACE UTILIZATION

1. By increasing the height of single storied structures to 4.2-4.5m, instead of 2.8-3.0m, a loft can be inserted to create more living space inside the house. Storage or living space can also be created under the pitch of a sloping roof. All such lofts and mezzanines should be supported on vertical structural members or walls.

2. Ladders, beds, seating places, etc. could be designed to double their usability as storage spaces.

3. Brick walls can be modulated in such a manner that they can double as storage spaces. Instead of a complete single brick wall, it can be half brick thick with piers of one and half brick thickness. This will save material and also create niches for storage, saving on furniture costs.
2.7 MAINTENANCE

1. Simple painting of the house on the external surface and of all structural members will improve the life of the house.

2. Inhabitants should be watchful for three stress signs: leakages, bends & cracks, corrosions & rots. Immediate remedial measures should be taken when such stress signs are noticed. Leakage sources should be plugged, members with bends and cracks should be replaced or strengthened with additional members, and for corrosions and rots, adequate steps should be taken depending upon the damage. If the damage is less, simple removal (scrubbing in case of corrosion and complete cutting out in case of wood) and finishing (painting in case of steel and new strengthening member in case of wood) could be used. When the damage is greater, affected members need to be replaced.

3. Inhabitants should also be watchful against pests like termites and rats, which tend to harm the structure. While termites damage wooden members, rats tend to burrow holes affecting the foundations and causing sinking.

4. Water logging near the house should also be prevented.
2.8 COSTS

Cost Data – Dry Construction

<table>
<thead>
<tr>
<th>No.</th>
<th>Items</th>
<th>Rate '11</th>
<th>Quantity</th>
<th>Unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Foundation/ Plinth</td>
<td>155.62</td>
<td>6.30</td>
<td>cum</td>
<td>980.41</td>
</tr>
<tr>
<td>1</td>
<td>Excavation (450mm wideX 1m heightX 14m)</td>
<td>2 Rubble Soling (150-200mm)</td>
<td>591.09</td>
<td>1.80</td>
<td>1063.96</td>
</tr>
<tr>
<td>3</td>
<td>Filling the excavated material and rammling for plinth (300mm)</td>
<td>59.13</td>
<td>3.60</td>
<td>cum</td>
<td>212.88</td>
</tr>
<tr>
<td>4</td>
<td>PCC (75mm thick) (15-10)Plinth;3x4m, Foundation: 0.3mX14m</td>
<td>3538.34</td>
<td>1.22</td>
<td>cum</td>
<td>4299.08</td>
</tr>
<tr>
<td>5</td>
<td>Brick (230mm wall X1.5m highX14m)</td>
<td>3999.37</td>
<td>4.83</td>
<td>cum</td>
<td>19316.96</td>
</tr>
<tr>
<td>6</td>
<td>Floor finish - marble mosaic set in grey cement</td>
<td>440.99</td>
<td>12.00</td>
<td>sqm</td>
<td>5291.87</td>
</tr>
<tr>
<td>7</td>
<td>Damp Proof Course (40mm thick)</td>
<td>268.92</td>
<td>16.00</td>
<td>sqm</td>
<td>4302.80</td>
</tr>
<tr>
<td>8</td>
<td>Built up steps in brick (0.6mX0.4mX0.45m)</td>
<td>5175.03</td>
<td>0.11</td>
<td>cum</td>
<td>558.90</td>
</tr>
<tr>
<td>B</td>
<td>Walls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Timber Stud Frame (2”x3”, @ 600mm c/c), with all materials required</td>
<td>16969.56</td>
<td>1.02</td>
<td>cum</td>
<td>17308.95</td>
</tr>
<tr>
<td>2</td>
<td>for fixing (Verticals: 22nosX8mhtX0.05mX0.075m; Horizontals:</td>
<td>518.74</td>
<td>84.00</td>
<td>sqm</td>
<td>43573.99</td>
</tr>
<tr>
<td>3</td>
<td>10nosX14mX0.05mX0.075m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Corrugated Sheet Metal Cladding (with all materials required for</td>
<td>19.86</td>
<td>4.00</td>
<td>sqm</td>
<td>79.42</td>
</tr>
<tr>
<td>5</td>
<td>fixation), with plastic backing for insulation, red-oxide paint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Water proofing of members</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Plywood Shutter</td>
<td>1501.61</td>
<td>1.89</td>
<td>sqm</td>
<td>2838.04</td>
</tr>
<tr>
<td>2</td>
<td>600mmx600mmx4nos. (plywood Shutter)</td>
<td>1501.61</td>
<td>1.44</td>
<td>sqm</td>
<td>2162.32</td>
</tr>
<tr>
<td>D</td>
<td>Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Timber Jolts (3”x4” @ 600mm c/c) (7nosX3mX0.075X0.1)</td>
<td>16969.56</td>
<td>0.16</td>
<td>cum</td>
<td>2672.71</td>
</tr>
<tr>
<td>2</td>
<td>Plywood floor (red oxide coated)</td>
<td>1141.72</td>
<td>12.00</td>
<td>sqm</td>
<td>13700.64</td>
</tr>
<tr>
<td>3</td>
<td>Corrugated Metal Sheet, with J bolts, washers, etc. Assume</td>
<td>518.74</td>
<td>14.00</td>
<td>sqm</td>
<td>7262.33</td>
</tr>
<tr>
<td>4</td>
<td>appropriate overlaps between roof sheets</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Metal ladder (3000mm high, 450mm wide)</td>
<td>509.18</td>
<td>3.00</td>
<td>rmt</td>
<td>1527.55</td>
</tr>
<tr>
<td></td>
<td>GRAND TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>13550.15</td>
</tr>
</tbody>
</table>

Existing cost per square foot = INR 425 to 450 (USD 9.50 to 10.00)

Existing maintenance cost per year = INR 15,000 to 20,000 (USD 350 to 450)

Recommended cost per square foot = INR 525 (USD 11.60)
## Cost Data – Wet Construction

<table>
<thead>
<tr>
<th>No.</th>
<th>Items</th>
<th>Rate '11</th>
<th>Quantity</th>
<th>Unit</th>
<th>Unit Total</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Foundation/Plinth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Excavation (upto 1m)</td>
<td>155.62</td>
<td>6.30 cum</td>
<td>980.41</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Rubble Stone (150-200mm)</td>
<td>591.09</td>
<td>1.80 cum</td>
<td>1063.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Filling the excavated material and ramming for plinth (300mm)</td>
<td>59.13</td>
<td>3.60 cum</td>
<td>212.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PCC (75mm thick) (1.5:1) Plinth: 3mx4m, Foundation: 0.3mx14m</td>
<td>3538.34</td>
<td>1.22 cum</td>
<td>4299.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Brick (230mm wall X1.5m high X14m)</td>
<td>3999.37</td>
<td>4.83 cum</td>
<td>19316.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Floor finish - marble mosaic set in grey cement</td>
<td>440.99</td>
<td>12.00 sqm</td>
<td>5291.87</td>
<td></td>
<td></td>
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<td>7</td>
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<td>268.92</td>
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<td>4302.80</td>
<td></td>
<td></td>
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<td>8</td>
<td>Built up steps in brick (0.6mx0.4mx0.45m)</td>
<td>5175.03</td>
<td>0.11 cum</td>
<td>558.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Walls</td>
<td>92101.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Brick Wall (half brick thick)</td>
<td>608.03</td>
<td>84.00 sqm</td>
<td>51074.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Internal Plaster (1/3, 6mm thick)</td>
<td>95.56</td>
<td>84.00 sqm</td>
<td>8026.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>External Plaster (1/4, 15to20mm thick, rough cast)</td>
<td>333.33</td>
<td>84.00 sqm</td>
<td>27999.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Provide and install door (2100x900), 1 no. (Plywood shutter)</td>
<td>1501.61</td>
<td>1.89 sqm</td>
<td>2838.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Provide and install windows (600x600mm) 4 nos. (plywood Shutter)</td>
<td>1501.61</td>
<td>1.44 sqm</td>
<td>2162.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Floor</td>
<td>26474.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Metal Jolts (T sections of 70x70) (7nosx3mX7.14kg)</td>
<td>70393.24</td>
<td>0.16 MT</td>
<td>11086.94</td>
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<td></td>
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<tr>
<td>2</td>
<td>Stone floor (ladi-coba-ladi)</td>
<td>1237.28</td>
<td>12.00 sqm</td>
<td>14847.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Plywood hatch door in floor (600x600mm, with all fasteners, bolts, hinges etc.)</td>
<td>1501.61</td>
<td>0.36 sqm</td>
<td>540.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Roof</td>
<td>10635.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Timber Jolts (3&quot;x4&quot; @ 600mm c/c) (7nosx3mX0.75x0.1)</td>
<td>16969.56</td>
<td>0.16 cum</td>
<td>2672.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Corrugated Metal Sheet (with J bolts, washers, etc.), Assume appropriate overlaps between roof sheets</td>
<td>518.74</td>
<td>14.00 sqm</td>
<td>7262.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Plastic Sheet cover, fastened at corners</td>
<td>50.00</td>
<td>14.00 sqm</td>
<td>700.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Metal ladder (3000mm high, 600mm wide)</td>
<td>509.18</td>
<td>3.00 rmt</td>
<td>1527.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>GRAND TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>166765.73</td>
</tr>
</tbody>
</table>

**Note 1:** Existing wet construction techniques include the use of reinforced cement concrete or steel frames. This results in high costs for materials and labor. A 3m x 4m home is small, and does not require the use of such framing techniques – a simple load-bearing structure built of good quality brick with appropriate external finishes offers an effective construction solution, and is cost effective relative to the use of RCC or steel. Often, poor quality bricks with non-plastered surfaces are used; this yields lower per square foot costs; the integrity of the home is compromised, however. The study’s recommendation is to use high quality bricks for load-bearing construction as the primary wet construction technique.

Existing cost per square foot = INR 450 to 735 (USD 10.00 to 16.50). See Note 1.

Existing maintenance cost per year = INR 10,000 to 15,000 (USD 220 to 330)

Recommended cost per square foot = INR 645 (USD 14.35)
Recommended cost per square foot = INR 575 (USD 12.75)

Existing cost per square foot = INR 450 to 500 (USD 10.00 to 11.00)

Existing maintenance cost per year = INR 15,000 to 20,000 (USD 350 to 450)
**Cost Data - Break up by Component**

The following diagram illustrates component-wise cost options for a 3mX4m unit. It is helpful in making decisions regarding the choice of material and systems of construction.

<table>
<thead>
<tr>
<th>FOUNDATION &amp; PLINTH</th>
<th>WALL OPTIONS</th>
<th>FLOOR OPTIONS</th>
<th>ROOF OPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber frame with corrugated Sheets</td>
<td>Steel Frame with corrugated Sheets</td>
<td>Timber Joists with plywood</td>
<td>Timber frame with corrugated Sheets</td>
</tr>
<tr>
<td>INR 36,000</td>
<td>INR 74,000</td>
<td>INR 10,600</td>
<td></td>
</tr>
<tr>
<td>Brick Wall</td>
<td>Steel Joists with stone (ladi coba ladi)</td>
<td>INR 26,000</td>
<td></td>
</tr>
<tr>
<td>INR 39,500</td>
<td>INR 26,000</td>
<td></td>
<td>Steel Frame with corrugated Sheets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>INR 18,500</td>
</tr>
</tbody>
</table>
2.9 COST AND BENEFIT

The Trade-off: Higher upfront cost but longer term gains

The details and assembly techniques recommended in this report clearly increase the total upfront cost of the house, even if marginally so. However, the annual recurring maintenance costs for a house built using conventional methods, if added up over a one-year period, outweigh this upfront cost.

Given the varied quality of the houses in these settlements, and the unpredictability of flooding events (in terms of frequency, the magnitude, as well as the resulting damage), it is impossible to accurately capture exactly how much each family spends on maintenance. The adjacent Box is a simplified illustration which quantifies once such trade-off: the real cost of using versus not using a water-proofing compound (Black Japan).

Moreover, families with limited or unpredictable sources of income often choose not to regularly invest in repairs and maintenance, which leaves their homes vulnerable to –
- Seepage of water from the floor, through capillary action.
- Damp living conditions, which are likely to have health impacts.
- Damage to structural elements, due to water seepage; over time this will leave the home open to the risks of structural failure.
- Reduced productivity, in cases where homes are also workshops or production units.

The cost of Black Japan waterproofing for a two-storey house of 3m x 4m, built of dry materials is approximately INR 368 (see details below).

- Total Black Japan required = 18.375 sm (Foundation – 17sm, Vertical Studs – 1sm, Horizontal – 0.375 sm)
- Total cost incurred @ INR 20/sm of Black Japan = INR 368

Note: the above assumes 2”x3” horizontal and vertical timber studs spaced at 600mm; 600mm deep foundation of brick walls, rammed earth, stone bed and concrete floor.

If Black Japan is not used, the following are likely to occur over 1 to 2 years –
- Damage to timber structural members due to seepage of water from the foundations and from adjoining brick walls.
- Seepage of water from the ground also results in compromised living conditions and damage to personal property.

The above conditions can be remedied through spot repair of damaged timber members by removal of damaged parts, or replacing with new members that are fastened to the existing members (adequate overlap must be provided between the new and existing members).

The remedial cost assuming only a quarter of the timber members are impacted, up to a depth of 300mm, is INR 650 (see details below):

- Material: (Jungle wood @ INR 15,000 per cubic meter, 2.7mX5cmX7.5cm) = INR 150. Note: (If better quality wood is used, then it will cost INR 400 to 600
- Labor: (@ INR 250 per day for 2 days) = INR 500
- Total - INR 650

This will address the problem only temporarily, and compromises the structural integrity of structural members.

This illustration assumes minimal damage; the exact cost to remedy damaged members is hard to quantify, due to the unpredictable nature of water seepage. It is safe to say, however, that this will become a recurring event. It is not hard to see how, over a relatively short period, the costs of repair to timber members will substantially outweigh the cost of Black Japan water proof compound at the outset.

Note: Rate of Black Japan adapted from Schedule of Rates – 2010, Madhya Pradesh Water Resources Department. Other rates adapted from District Schedule of Rates - 2009, Maharashtra Public Works Department, Mumbai. All rates are inflated at 11.44% (average inflation rate) to obtain current values.
### 2.10 Materials, Procurement and Methods of Construction

The following table describes the predominant material palette and its use, quality, size, treatment, cost and places of procurement. Information for this table is obtained from case studies in Shivaji Nagar, Mumbai.

<table>
<thead>
<tr>
<th>Material</th>
<th>Type of construction</th>
<th>Building component in which material is used</th>
<th>Quality / type / size / treatment</th>
<th>Cost</th>
<th>Places of procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCC</td>
<td>Wet construction</td>
<td>Foundation Plinth Vertical structural elements Horizontal structural elements</td>
<td>less time given for curing Rs 400 per sq ft. about 1 week</td>
<td>In situ construction by local contractors</td>
<td></td>
</tr>
<tr>
<td>brick</td>
<td>Wet construction</td>
<td>Foundation Plinth Vertical structural elements Horizontal structural elements</td>
<td>230mm X 110mm X 57mm</td>
<td>Rs. 3.80 per brick but by the time it reaches the final destination it becomes Rs. 4.50 per brick</td>
<td>Belapur kiln to highway shops or other local outlets. Second hand bricks come from former construction sites</td>
</tr>
<tr>
<td>steel</td>
<td>Wet construction</td>
<td>Vertical structural elements Horizontal structural elements Vertical cladding elements</td>
<td>4&quot; x 3&quot;, 3&quot; x 3&quot;, 3&quot; x 2&quot; treated with red oxide</td>
<td>from Rs.25 per kilo to Rs.40 per kilo depending on the gauge</td>
<td>It is usually bought either from Kurla or from shops located near the site which get its supplies from Kurla</td>
</tr>
<tr>
<td>sand</td>
<td>Wet construction</td>
<td>Foundation Vertical structural elements Horizontal structural elements</td>
<td>comes by truck</td>
<td>Rs. 6,000 per truck - Rs. 16,000 per truck</td>
<td>Sand comes from former construction sites or from Sopara</td>
</tr>
<tr>
<td>bamboo</td>
<td>Dry construction</td>
<td>Vertical structural elements Sizes upto 8 - 12 ft</td>
<td></td>
<td>Rs. 30 - Rs. 40 per ft. (approx. cost of bamboo structural system for an avg. size house is Rs. 50,000) 12' - Rs 400 per piece 8' - Rs. 300</td>
<td>From construction sites in the city disposing off their scaffolding material, from recycling market in Kurla or from local shops</td>
</tr>
<tr>
<td>timber</td>
<td>Wet construction</td>
<td>Vertical structural elements Horizontal structural elements Roof structural elements</td>
<td>4&quot; x 3&quot;, 3&quot; x 3&quot;, 3&quot; x 2&quot; 4&quot; x 3&quot; - 40 / ft 3&quot; x 3&quot; - 20 / ft 3&quot; x 2&quot; - 17 / ft</td>
<td>From demolition sites, from recycling market in Kurla or from local first hand and second hand shops</td>
<td></td>
</tr>
<tr>
<td>plywood</td>
<td>Wet construction</td>
<td>Vertical cladding elements</td>
<td>comes in varying sizes 1/2&quot;</td>
<td>Rs. 25 per sq ft. for old plywood</td>
<td>From demolition sites, from recycling market in Kurla or from local first hand and second hand shops</td>
</tr>
<tr>
<td>Dry construction</td>
<td>Roof cladding materials</td>
<td>with the maximum length thick being 8 ft.</td>
<td>Rs. 40 per sq ft. for new plywood.</td>
<td>From demolition sites, from recycling market in Kurla or from local first hand and second hand shops</td>
<td></td>
</tr>
<tr>
<td>AC sheets</td>
<td>Wet construction</td>
<td>Vertical cladding elements</td>
<td>width is about a metre and length 3 m</td>
<td>Rs. 550 per sheet</td>
<td>From demolition sites, from recycling market in Kurla or from local first hand and second hand shops</td>
</tr>
<tr>
<td>Dry construction</td>
<td>Roof cladding materials</td>
<td>&amp; length 3 m</td>
<td>Rs. 550 per sheet</td>
<td>From demolition sites, from recycling market in Kurla or from local first hand and second hand shops</td>
<td></td>
</tr>
<tr>
<td>tarpaulin</td>
<td>Wet construction</td>
<td>Roof cladding materials</td>
<td>8’ width, comes in rolls</td>
<td>Rs. 40 - 50 / m</td>
<td>locally available</td>
</tr>
</tbody>
</table>
PART 3
ALTERNATIVE MATERIALS AND METHODS

3.1 Bamboo structure
3.2 Tire foundation and wall
3.3 Walls of plastic bottles
3.4 Walls of aluminum cans
3.5 Glass bottles for day lighting
3.6 Furniture of paper, bottles, pipes, cans
3.7 Fly Ash
3.1 BAMBOO STRUCTURE

Overview

Bamboo is a lightweight material, which requires a very minimal foundation. Basic components for construction of a bamboo house include wire, bolts, chicken mesh, and cement, all of which are relatively inexpensive and easily available.

Selecting construction quality bamboo:
- Depending on the species, 3 to 5 year old bamboo is best for construction purposes.
- Do not expose the bamboo poles to direct sun, moisture and rain.
- Use only straight portions from the bamboo culms for construction poles.
- Poles should be treated to protect against insects and fungus.

Bamboo Structure - Construction Process

STEP ONE: A trench of min depth 0.5 m and min width of 0.3 m is excavated. The trench to be filled with field stones and cement grout in layers. Plinth course be completed in concrete. The height of plinth should be 600 mm above ground level.

STEP TWO: Erect bamboo columns in place and embed a minimum of 250 mm into the plinth course. The canes should be attached to the formwork to ensure vertical position during concrete casting.

Ideas and Images courtesy: http://www.staff.city.ac.uk/earthquakes/Bamboo/Bamboo.htm#Third%20link (11.07.11, 12.20am)
http://www.staff.city.ac.uk/earthquakes/Bamboo/Bamboo.htm#Third%20link (11.07.11, 5.16pm)
http://www.oxheyworld.com/india/houses.htm (11.07.11, 6.38pm)
**Bamboo Structure - Construction Process**

**STEP THREE:** Erect main posts at all corners, and also along the house envelope with a spacing of about 1.2m. Mild steel anchor are fixed to the bamboo posts at intervals of 150mm. A timber roof top plate is then fixed to the top of the bamboo posts.

**STEP FOUR:** Construct infill walls between the vertical bamboo columns. Split bamboo grids are assembled by rope or wire ties and are fixed to plinth and bamboo posts.

**STEP FIVE:** Fix a chicken steel wire mesh to the grids: this will reinforce the bamboo grids, as well as to provide a base for the mortar. Cement based mortar is then plastered on top to provide overall stability to the wall infill. The finished wall thickness is about 50 mm thick.
**STEP SIX:** The roof should ideally be as light as possible. Using steel clamps, fix the rafters to the timber top beam. Bamboo mat board (BMB) gussets, in combination with mild steel (MS) bolts, are used for the truss-rafter joints. Use smaller diameter canes for the purlins.

**STEP SEVEN:** Fix purlins, of smaller diameter canes.

**STEP EIGHT:** Use bamboo mat corrugated sheets (BMCS) or GI sheets for roof cladding. Anchor the sheets to the purlins with J bolts. A roof overhang of 400 mm is recommended. Use BMB also for doors and window shutters.
Bamboo Structure - Typical Details

A  Inserting short, smaller diameter bamboo pole to strengthen bamboo member at a joint.

B  Detail of bamboo pole and timber ring beam

C  Detail of roof truss and ring beam

End profiles of bamboo poles

Washer and nut  
Ring beam

12mm anchor bolt

Bamboo pole column, min. 100mm dia

Timber ring beam 70mm x 140mm

Bamboo mat board

6mm L clamp

8mm MS through bolts

12mm anchor bolt

70x140mm timber ring beam (typ.)

100mm bamboo pole column
3.2 TIRE FOUNDATION AND WALLS

Overview

Old or discarded automobile tires can be used to make foundations in places where the soil has good compressive strength. The tires used must preferably be of the same size.

Step-wise construction

STEP 1: Make a pit of width equal to the diameter of the tire. Ram well and make compact. Lay out a course of tires to establish the optimum lay with the least spacers. Half tires may be used to satisfy the required dimension. However, they are not to be used at the ends or corners.

STEP 2: Use sticks to prop the tyre “open” and fill with dirt/earth. Remove sticks and pound the earth to compact. Plumbing lines may be placed between/ along the tyres, if needed, and pipe chases may be installed during tire wall construction.

STEP 3: Pour concrete over this layer. Set reinforcement bars into alternate tyres with 5” of to be fitted on top

STEP 4: Install treated 2” X 12” sill plate and non-treated bond beam. This will ensure better construction joints for superstructure.
Plastic Bottles – Typical Construction Details

Step 1

Step 2

Step 3

Step 4

Image courtesy: http://gregdalbey.blogspot.com/2009_08_01_archive.html (10.7.11, 11.18pm)
3.3 PLASTIC BOTTLES

Overview

House made with plastic bottles

Bottles can also provide light.

Step-wise construction

STEP 1: Prepare the bottles. Wash each bottle thoroughly. Fill them with sand or another appropriate infill.

STEP 2: Lay them out to dry.

STEP 3: Construct the wall layer by layer. Use mortar to fill the gaps between bottles. Use string guides to maintain straight lines.

STEP 3 Vertical Alternative: Create the bottom row of your wall. Attach the bottles to one another while laying them on the floor to ensure that the bottom of the wall is level. For a vertical stacking of bottles, rubber solution can be used to join the bottles to one another. Let the solution on each stacked bottle dry completely before adding the next layer.

The bottles can be bound between layers of chicken mesh, which is then attached to a metal frame.

Up to three layers of cement mixed with sand are applied to the outside of the bottles.

Stacks of bottles can be used as furniture elements too. The wall can also be modulated to accommodate for shelves, cupboards, etc.
Plastic Bottles – Typical Construction Details

Step 1

Step 2

Step 3

Vertical Alternative: Walls

Idea and Images courtesy: inspirationgreen.com
3.4 ALUMINUM CANS

Overview

Methods:

MODULAR: One of the methods of using aluminium cans is by constructing a module as shown above.

CRUSHED: Another way of using aluminum cans is by crushing them. Compression increases the building strength.

INDIVIDUAL UNITS: Aluminum cans can also be used by laying them horizontally in a concrete mix. The cans are staggered with batches of concrete are used between rows. The method for stacking the cans involves creating a row of cans separated by hand-formed lumps of concrete. The layout of a row is can, concrete, can, etc. This is then repeated, except that the alternating pattern is reversed, so that every can is laid on top of a concrete “lump” below it.

COMBINED: Aluminum cans can also be used in combination with glass bottles for the construction of a wall.
Aluminium Cans – Typical Construction Methods

As a module

Aluminum Cans as individual units

Crushed Aluminum Cans

In combination with glass bottles

Ideas and Images courtesy: http://inspirationgreen.com/building-blog
3.5 GLASS BOTTLES

Overview

STEP 1: Select bottles, preferably of the same size. However varying designs can be achieved with different shapes, sizes and colors.

STEP 2: Prepare the bottles by removing the labels and washing each thoroughly with soap and warm water. Leave caps on empty bottles only if they are completely clean and dry inside.

STEP 3: Create the bottom row of the wall. Use the glass bottle as a masonry unit and bind with sand, adobe, cement, stucco, clay, plaster or mortar.

STEP 4: Reinforcement bars can be set in foundation to add structural stability; the bars can continue vertically to reinforce the framework for the glass wall.

STEP 5: Build the sides of the wall to form a frame.

STEP 6: Fill in the wall frame. Be sure that each bottle is ‘glued’ (with the binding material) wherever it touches another bottle. Although this is not strictly necessary for the wall to stay up, the wall will be more sturdy the more mortar it has.

Step-wise construction

Glass bottles for daylighting
Glass Bottles – Typical Construction Details

Glass Bottles as Masonry Unit

Glass Bottles as Wall Fills

Image courtesy: http://inspirationgreen.com/glassbottlewalls.html (28.06.11, 5.59pm)
3.6 FURNITURE

Paper

Paste of waste paper being made to make furniture

Sofa made from paper mache

Framework of bed being made from paper

Completed double bed

Chair made from cardboard

Ideas and Images courtesy: http://www.peoplepotential.org.uk/page8.htm
**Bottles**

Plastic Bottles used to make seating and table

Bottle caps used to create separations

Ideas and Images courtesy: http://www.peoplepotential.org.uk/page8.htm

**Pipes**

Table made from PVC pipes

Unit for storage made out of pipes

Ideas and Images courtesy: http://www.furnituria.com/2011/05/29/pvc-pipe-furniture-for-storage-units/

**Aluminum Cans**

Aluminum Cans crushed to make furniture

Beer Cans used to make sofa

3.7 FLY ASH

Overview

Fly ash is an inorganic product of fusion after combustion of coal in boilers of thermal power plants and is produced in huge quantities. Ways in which fly ash can be utilized for construction:

Cellular Light Weight Concrete (CLC) Blocks

Cellular Light Weight Concrete (CLC) blocks can substitute bricks and conventional concrete blocks for building. Using CLC, panels for walls & roofs can also be produced.

Advantages:
Better strength to weight ratio.
Reduction of dead load resulting in reduction in foundation size.
Better acoustical and thermal insulation. Saving in consumption of mortar.
Higher Fire Rating.

Fly Ash-Sand-Lime-Gypsum Bricks/Blocks

Fly Ash can be used in the range of 40-70%. The other ingredients are lime, gypsum, sand, stone dust/chips etc.

Advantage over burnt clay bricks:
Lower requirement of mortar in construction
Plastering over brick can be avoided.
Controlled dimensions, edges, smooth and fine finish & can be in different colors using pigments.
Cost effective, energy-efficient & environment friendly (as avoids the use of fertile clay).

Clay-Fly Ash Bricks

Fly Ash content can be 20 to 60% depending on the quality of clay. Process of manufacturing is same as for the burnt clay bricks.

Advantages:
Fuel requirement is considerably reduced as fly ash contains some percentage of unburnt carbon.
Better thermal insulation.
Cost effective and environment friendly.
Fly Ash

Buildings made with fly ash bricks

Fly Ash-Sand-Lime-Gypsum Bricks

Fly Ash substitute cement in a concrete mix

Structure using Cellular Light Weight Concrete Blocks

Construction using Clay-Fly Ash bricks

Fly Ash based Polymer Composite as a substitute for wood

Ideas and Images courtesy: inspirationgreen.com
Development of Fly Ash Based Polymer Composites as Wood Substitute

Fly ash based composites have been developed using fly ash as filler and jute cloth as reinforcement. After treatment, the jute cloth is passed into the matrix for lamination. This can be applied for many applications like door shutters, partition panels, flooring tiles, wall paneling, ceiling, etc.

Advantages:
With regard to wood substitute products, it may be noted that the developed components / materials are stronger, more durable, resistant to corrosion and above all cost effective as compared to the conventional material i.e. wood.

Portland Pozzolana Cement (Fly Ash based)

Upto 35% of suitable fly ash can directly be substituted for cement as blending material. In India, present cement production per annum is comparable to the production of Fly Ash. Hence even without enhancing the production capacity of cement; availability of the cement (fly ash based PPC) can be significantly increased.

Advantages:
Addition of fly ash significantly improves the quality & durability characteristics of resulting concrete.
INFORMAL HOUSING: REDUCING DISASTER VULNERABILITY THROUGH SAFER CONSTRUCTION

WORLD BANK, DECEMBER 2011
(Funded by TFESSD under Component 2 of “Addressing Climate Change with Low Cost Green Housing”)