sheltering
New sustainable shelter solutions for disaster relief

! Cardboard !

Daan van Kinderen
Ferry Klos
Introduction

Concept - tests - improved design - Conclusions

Issues
Research design

Shelters
- commercial shelters
- great variety

Left: A small selection from the range commercial shelters
What are the problems with the current shelters?

• Ventilation / infiltration;
• insulation;
• costs;
• sustainability;
• Construction.

Offered shelters are often not tested and certified

Requirements (Shelter Standards) are not clearly specified
right: research model research project

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issues research design

right: research model research project

INLEIDING
Material selection
shape
package Structure
Connectivity
roof cover
anchoring
prototype

**design Goals**
1. Suitable for a hot, humid climate (tropical savanna);
2. Improved living comfort, good indoor climate;
3. Intended life = 12 months;
4. Main Construction Material = paperboard;
5. Recyclable;
6. Local produce.
Why cardboard?

- Low cost;
- Available worldwide;
- Quick and easy production;
- Recyclable;
- Sustainable renewable raw material (wood);
- Lightweight.
Type of cardboard?

Corrugated cardboard is very appropriate because:
- Worldwide availability;
- High strength (in one direction) at low volume;
- Low cost.

Honeycomb Cardboard \u0026 FlexWave©: not available worldwide
Solid board: poor mechanical properties and great weight

Final choice: Corrugated cardboard, 3.8 mm C-wave

*V.l.n.r.:* honeycomb cardboard, corrugated cardboard, solid board, FlexWave©
Form map?
Hexagon is beneficial because:
• Favorable floor for 5 people;
• Floor area ratio / materials (Archimedean body);
• Strong, stable form;

Square and rectangle: Grand facades, high bending stiffness required
Dome: too complex form

Final choice: Hexagonal floor plan, Side length 2640 mm, height 1540 mm wall, floor area 17.5 sqm
cavity Construction
- Highly ventilated cavity;
- Ventilation of the inner space by means of ventilation valves;
- Ventilation under roof cover (tropical roof).
hinge system
• Foldable by S-shaped hinges;
• Limited transport volume.

right: Foldable wall with S-shaped hinges
stiffness
• Stiffness by triangular tubes at each end;
• Folding back of the hinges is prevented.
stiffness

• Stiffness triangular tubes at each end;
• Folding back of the hinges is prevented.
Type connections?
Tape is appropriate because:
- High tensile strength, high maximum shear stress
- Relatively durable, UV-resistant;
- Recording of deviations;
- Easy to use.

Glue: Not applicable location
Staple \u0026 molding compound: Only useful for temporary connection

Final choice: 3M bi-directional filament tape, 150 mm wide, 50m roll
Drainage / tropical roof
- Protection against rain ;
- Reflection solar radiation ;
- Exhaust heat ventilation under sail .
Material selection
shape
package Structure
Connectivity

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prototype

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constructive

• Anchoring to the ground;
• Remittance wind load (draw);
• Avoids controversy.

Tape-ring bottom wall + roof provides for the payment of spatter forces
Type anchoring?

Why ground anchors?
- Very high ultimate tensile strength (261 - 4820 kg);
- Lightweight (about 105 grams each);
- Low volume;
- Low cost (around €1.50 each)

Tent Pegs: high weight, large volume
Anchoring in base: not definitely needed a base plate
Digging: labor intensive, additional protection necessary

Final choice: Duck Bill 68 folding anchor
Duck Bill 68
1. Anchor in soil drifting with connecting rod;
2. Attract steel cable;
3. Guylines confirm and blocking.

CONCEPT
Material selection
shape
package Structure
Connectivity
roof cover
anchoring

prototype
- Used for building physical tests;
- Knowledge of materials;
- Building Order.

introduction - concept - Tests - improved design - Conclusions
Building Physics: flue Test

flue Test
- Visualizing movements;
- infiltration;
- Ventilation rate.

conclusions:
- Infiltration is large by seam roof (without roof fabric);
- Provision for draining ventilation is needed.

left: Indoor smoke during test
Ventilation Testing

- Ventilation rate determination;
- Determine cavity ventilation;
- Determine chimney effect;
- Mutual influence determine.

Building Physics:

flue Test
ventilation
Testing
metering
hotbox
constructive:
roof
wall

TESTS

introduction - concept - tests - Improved design - Conclusions

left: Measurement setup ventilation measurements
conclusions:
• Ventilation by thermal draft is too low (ca. 8.5 dm³/s requirement = min. 16 dm³/s);
• Ventilation cavity is minimal (approximately 23% of total air flow);
• Ventilation cavity has a negative effect on the ventilation rate;
• Infiltration is large (approximately 25% of the total air flow), Can be reduced by closing the roof canopy well to leave.

v.l.n.r.: Air Flow Meters, Placing insulation, heat source (4 pieces)
Building Physics:
flue Test
ventilation
Testing

metering
hotbox
constructive:
roof
wall

metering
• Determining average illuminance in space;
• Determining daylight factor.

conclusions:
• Overall brightness is sufficient (139 lux requirement = 100-200 lux);
• Dispersion is not optimal.

introduction - concept - tests - Improved design - Conclusions

left: points
right: light distribution in space
U value measurement (hotbox)

- Determine U-value wall panel;
- Determine U-value roof;

Conclusions:
- U-value = 4.13 m²K/W; (R = 0.24 W/m²K)
- U-value roof = 4.08 m²K/W; (R = 0.25 W/m²K)
- Performance 30% better than Ridge Attraction;
- U-value measurement prototype U = 1.61 m²K/W; (R = 0.62 W/m²K)

Building Physics:
- flue Test
- ventilation
- Testing
- metering

hotbox
constructive:
- roof
- wall

left: positioned as a hotbox
right: metering
roof: *bending strength*

- Determining bending strength wall panel.

Building Physics:
- flue Test
- ventilation
- Testing
- metering
- hotbox

constructive:
- roof
- wall

left: measurement setup flexural strength

right: computer analysis Deflection Idiana

introduction - concept - **tests** - Improved design - Conclusions
conclusions:

- Roof panel does not conform in terms of strength (71%);
- Roof panel does not in terms of deflection (20%);
- Roof panel has a weakness in the ridge, transverse ribs running internally not far enough.
Building Physics:
flue Test
ventilation
Testing
metering
hotbox

constructive:
roof
wall

Introduction - concept - **tests** - Improved design - Conclusions

- **roof: creep**
  - Determining deflection under sustained load

Conclusions:
- Bending creep continues to increase;
- Cardboard is unsuitable for long-term permanent loads.

*left:* graphics deflection - time (logarithmic scale)
Building Physics:
- flue Test
- ventilation
- Testing
- metering
- hotbox

constructive:
- roof
- wall

Wand: Deflection
- Determining bending strength wall panel

conclusions:
- Wall panel with adequate strength (124 %);
- Wall panel meets not in terms of deflection (25 %).

left: Measurement setup bending test wall panel
right: performance test
Wand: Compressive Strength

- Determining compressive strength wall panel
conclusions:
- Wall panel with adequate compressive strength (1247% !!);
- Wall panel meets not in terms of deflection (57%).
shape

- Sheet size prototype are too big;
- Surges are structurally too large;
- Floor area is too large (17.5 sqm).

improved design

- 12-angled floor plan, Side length 1250 mm, height 1500 mm wall
- favorable ratio materials - floor
- optimised plate dimensions
issues:
• S-shaped ribs are not machined to produce (double bonding);
• Insufficient rigidity of the panels;
• Hinges provide tension in the panel;
• Unfavourable wave direction in the transverse ribs (CD in the height of the panel);
• Too complex.
New package structure (*wall*):
- Grid of ribs and LTB restraints;
- Outside box clamps grid.

Advantages:
- Easy to manufacture;
- Raster allows for great stiffness (thus thinner panels; 60 mm);
- Simple in execution.
New package structure (roof):
• Grid of ribs and LTB restraints ;
• Outside box clamps Grid.

advantages :
• Only dry compounds;
• Tape - use about 50% less ;
• Saving cardboard: 45 % ;
• Construction time about 4 minutes per panel.
connection roof - wall
• Triangular tube connection is unnecessary;
• Seam finishing with tape.
Type transverse ribs?

Option 3 (MD - MD) is beneficial because:
- very high bending stiffness
- sufficient compressive strength
- simple production

Option 1: Compressive strength is too low;
Option 2: Compressive strength unnecessarily high;
Option 4\u0026 5: Production Technology not available worldwide.

Final choice: Double layer rib, MD in the height of the wall, 60 mm in width.
soil Protection

- XPE foammat;
- connection by tongue-groove;
- Recycled material;
- Simplicity: four types of plates;
- Draining action and protection against pests.

*left:* Floor space of four types of plates (G1 / G4 m)

*right:* XPE foammat

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**soil Protection**
introduction - concept - tests - **improved design** - conclusions

**soil Protection**

*left:* slot in base plates  
*above:* Placing wall panels slot  
*right:* Seal seam with tape - ring
Cross-ventilation

- Two oppositely disposed door openings;
- Wind Trim and suction over the openings.

**left:** Wind form factors at the shelter

**right:** Trim and suction over the doorways

**Introduction - Concept - Tests - Improved Design - Conclusions**

**Principle**

- Coating
- Transport
- Building
- Sequence
door panel
• Adjustable ventilation slide;
• Custom grid wall panel.

left: door panel exterior view
Middle: door panel inside view
right: internal grid wall panel with door
polymers
• Bio - polymers: Protein, starch, DNA, lignin, rubber etc;
• Synthetic polymers: Bakelite, PU, PVC, PTFE, PS, PP etc.;
• Long chains made up of monomers;
• Chains are not biodegradable.
Polyethylene (PE)

- Two types: LDPE and HDPE;
- Contains no toxic substances;
- Known from the packaging industry;
- Recyclable;
- Eventually use as a fuel (2 tons of residual waste = 1 tonne petroleum).

left: equation PE
right: a raw material for recycling

introduction - concept - tests - **improved design** - conclusions
additives
• Alters the properties of a polymer;
• Additions for:
  • hardness;
  • UV-resistance;
  • Colour / surface;
  • Fire resistance;
  • Etc.
additives: Bio-degradable plastics
• Additive acts as a catalyst;
• Enter into force when placed in high microbial environment;
• Makes chains degradation by microbes as possible;
• Complete breakdown within 2 months;
• Emissions: methane gas and water.
additives: *Self-healing plastics*

- Nano-capsules with filler;
- Curing by ceramic catalyst;
- Damage recovers within seconds;

Product commercially available within five years.

*right:* action *self-healing plastics* according to Scott White
Transportation by container (20 ft), 40 shelter packages per container
Structure in 11 steps:

1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1° Half placing roof;
8. roof cover places;
9. 2° Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: Places ground plane
Structure in 11 steps:

1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. roof cover places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: places ribs
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. roof cover places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: Fold edges close

introduction - concept - tests - improved design - conclusions
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. roof cover places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: Wall panels in ground plane places
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. roof cover places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: Finishing seams between panels; tape - ring place
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1° Half placing roof;
8. roof cover places;
9. 2° Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: ribs sites
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. roof cover places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: folding edges
Structure in 11 steps:

1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1\textsuperscript{e} Half placing roof;
8. Roof cover places;
9. 2\textsuperscript{e} Half placing roof;
10. Tape - ring upper side wall;
11. Roof cover tensioning.

Right: Temporary support with included stand
Structure in 11 steps:

1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1e Half placing roof;
8. Roofcurtain places;
9. 2e Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: Assemble chimney and roof curtain
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1<sup>e</sup> Half placing roof;
8. roof cover places;
9. 2<sup>e</sup> Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

right: placement 2<sup>e</sup> half roof
Structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1<sup>e</sup> Half placing roof;
8. roof cover places;
9. 2<sup>e</sup> Half placing roof;
10. Tape - ring upper side wall;
11. roof cover tensioning.

*right*: placement tape - ring eaves
structure in 11 steps:
1. Lay ground level;
2. Assemble wall panels;
3. Placing wall panels;
4. Seams finished with tape;
5. Tape - ring bottom wall;
6. Assembling roof panels;
7. 1º Half placing roof;
8. roof cover places;
9. 2º Half placing roof;
10. Tape - ring upper side wall;

right: install ground anchors and tensioning roof cover