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UNDP PoWER Programme

**COOPERAZIONE
ITALIANA**

Cooperazione Italiana



CESVI Cooperazione e Sviluppo

Appropriate housing for Gash-Barka in Eritrea

**A short research on materials and techniques of construction
earth technology based suitable for lowland areas**

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Since the end of the last year CESVI – Cooperazione e Sviluppo has been involved in a programme of housing reconstruction financed by the Italian Government and managed by the UNDP – PoWER Programme, PMU office in Asmara.

On the end on May, adviser from UNCHS (Habitat) come to Eritrea to held a three days workshop devoted on earth construction technology and FC structures where we learn the principle of the earth blocks production and other topics.

After that we started our testing period at the begin of June to finish it at the end of August with a Workshop on low-cost housing for low-lands organized on the 28th-29th in Teseney and the 30th in Guluj.

The main objective of the research was to implement earth technologies for the construction of appropriate houses and the identification of alternatives roofing solutions for Gash-Barka, lowland area of Eritrea.

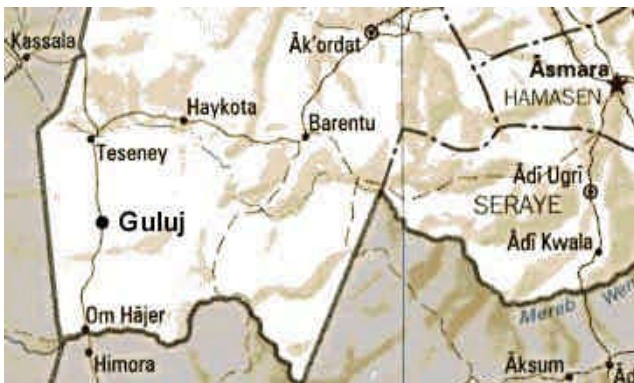
These are the main steps followed by this research:

- The analysis of the produced earth blocks on the habitat seminar in Asmara from the 17-19 of May 2001 in order to define the suitable stabilization for our production
- The analysis of the soil of Guluj in order to choose the suitable soil to produce earth blocks on site
- The analysis of the soil of Teseney as asked by UNDP – PoWER office
- The analysis of the produce blocks in Guluj (CEB, Adobes) in order to understand the quality of the production
- An assessment of previous implemented low-cost housing projects around Eritrea, in order to “learn from the past”
- The design and the construction of few prototypes in Guluj with different walling and roofing solution in order to evaluate a range of possible technique and material for construction

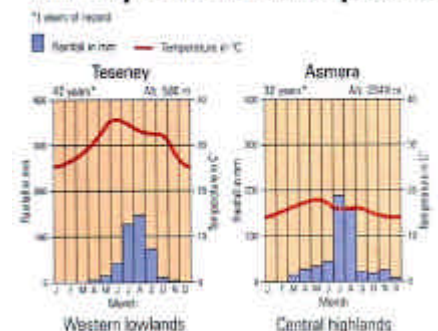
The results of our effort can be identified in the prototypes built in Guluj with different walling and roofing system.

But, we also believe that the analysis of the soil either of the earth blocks produced in Guluj, represent another important result as an evidence of the potential of earth techniques of construction in a place where no many resources are available.

Asmara, the 23rd of August 2001



Monthly rainfall and temperature



THE ANALYSIS OF THE BLOCKS PRODUCED WITH HABITAT

Earth blocks analysis of samples produced in Asmara during Habitat workshop

This are the earth blocks produce on the 18 of May 2001 in Asmara during the three days workshop hold in UNDP compound by Habitat technical adviser Dr. Rainer Nordberg with ten participants from NGOs and ministries active in the shelter construction in Guluj and Teseney.

n. of block	type of block	type of soil	Earth block ratio components						note
			SOIL	SAND	CEMENT	LIME	WATER	STRAW	
1	CEB	top soil	4						
2	CEB	top soil	4		0.25				too wet mixture
3	CEB	sub soil	4	6					
4	CEB	sub soil	4	6		0.5			
5	Adobe	top soil	4	4		1	2.5		
6	Adobe	top soil	4	4		1	2.5	0.3	
7	Adobe	top soil	4	3		1	2.5		
8	Adobe	top soil	4.5	3		1	2.5		too wet mixture
9	Adobe	top soil	5	5	0.5		2.5		
10	Adobe	sub soil	4				3	2	fermented for 1 night

After the drying period of few weeks we implemented the analysis of the produced blocks in order to find the suitable stabilization with the soil coming from Guluj.

The soil used to produce all blocks has been classified, later on, during the analysis of other soil sample from the same area as n.1. Therefore specification of this soil sample can be found in the following pages.

Sub- soil is a 2 m deep sample, while topsoil is from 20 cm deep from ground surface.

#	Type of block	Type of soil	Dimension of blocks (cm)	SSDB weight (Kg)	Entirely dry weight (Kg)	Entirely dry density (Kg/Mc)	Volume (Mc)	Moisture content (%)	Reading strength (KN)		One bed face area of the specimen (Sqm)	Strenght on surface unit (Mpa)
									SSDB (Wet)	Entirely dry		
1.	CEB	top-soil	29x14x11.5h	8.84	7.93	1,698	0.00467	11.600	-	50	0.041	1.2
2.	CEB	top-soil	29x14x11.5h	9.15	8.42	1,802	0.00467	8.700	120	-	0.041	3.0
3.	CEB	sub-soil	29x14x11.5h	9.15	8.54	1,830	0.00467	7.100	-	40	0.041	1.0
4.	CEB	sub-soil	29x14x11.5h	9.40	8.91	1,909	0.00467	5.400	-	40	0.041	1.0
5.	Adobe	top-soil	28x13x8.5h	5.37	5.32	1,720	0.00309	0.900	30	-	0.036	0.8
6.	Adobe	top-soil	27x27x8.5h	10.22	10.02	1,616	0.00620	2.000	-	300	0.073	4.1
7.	Adobe	top-soil	28x13x8.5h	5.09	5.05	1,633	0.00309	0.700	30	-	0.036	0.8
8.	Adobe	top-soil	28x13x8.5h	5.21	5.17	1,672	0.00309	0.700	30	-	0.036	0.8
9.	Adobe	top-soil	28x13x8.5h	5.70	5.59	1,806	0.00309	2.100	40	-	0.036	1.1
10.	Adobe	sub-soil	27x27x8.5h	8.53	8.11	1,308	0.00620	5.200	-	320	0.073	4.4

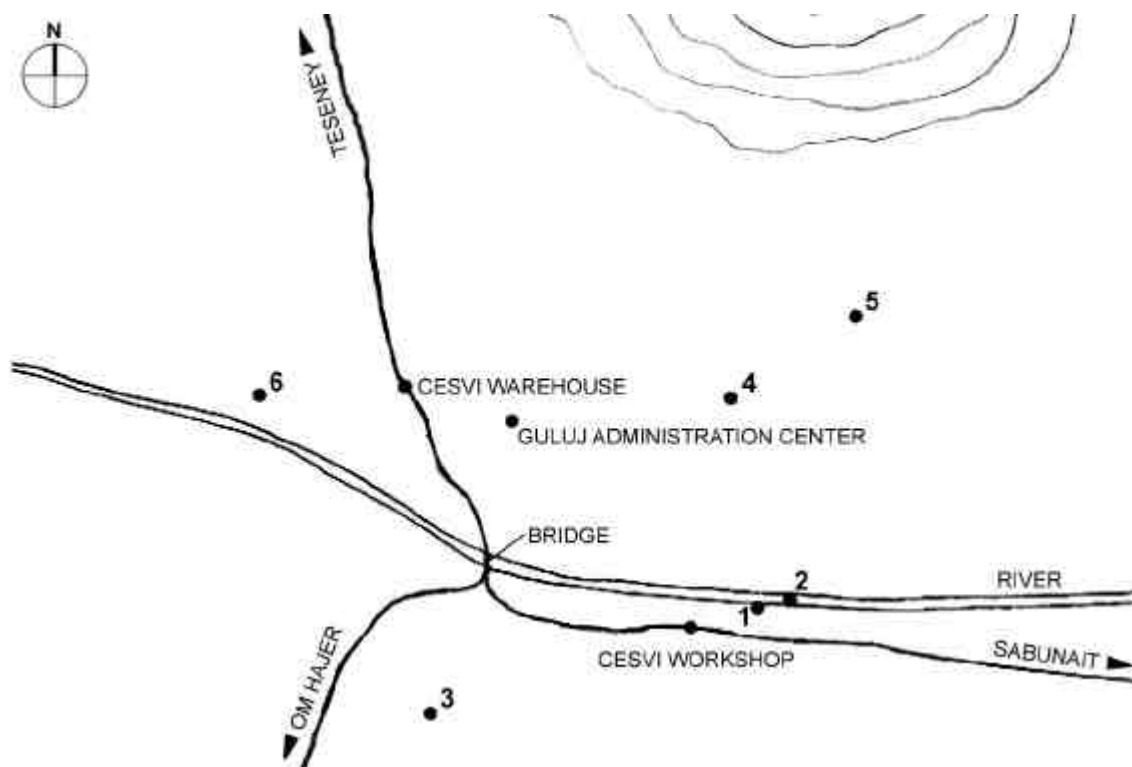
Analysis implemented from 6/6/2001 to 16/6/2001 by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

Because this results we decide to apply a stabilization with cement, that make the blocks stronger at the Wet compression test, while most of the sample produce they didn't allowed this test because they were melting once immersed in water.

THE ANALYSIS OF THE SOIL

Guluj Soil Map

In order to find a suitable soil for the earth block production we collected 8 sample of soil from Guluj visible on the map and recorder by coordinates for the future localization.



POINTS ON MAP	COORDINATES	NOTES
BRIDGE	N 14°44'19.0" E 036°43'24.2" Alt. 690 mt.	Crossing point between the main road and the river bed.
ADMINISTRATION CENTER	N 14°44'39.2" E 036°43'27.4"	Buildings of the administration as the town council and the courthouse.
CESVI WAREHOUSE	N 14°44'44.8" E 036°43'14.7"	CESVI warehouse and training area on the road to Teseney
CESVI WORKSHOP	N 14°44'11.0" E 036°43'41.5"	CESVI blocks factory on the road to Sabunait
SAMPLE 1	N 14°44'11.2" E 036°44'00.6" Alt. 696 mt.	Topsoil 20cm down from ground surface. Place on top of riverbed side, where surface cracks forming little canyons already exploited by local inhabitants to produce adobe.
SAMPLE 2	N 14°44'13.3" E 036°44'01.4" Alt. 687 mt.	Topsoil 20cm down from ground surface. Place on bottom of riverbed side, between the sandy riverbed and the clay soil of riversides.
SAMPLE 3	N 14°43'59.0" E 036°43'16.7" Alt. 691 mt.	Topsoil 20cm down from ground surface.
SAMPLE 4	N 14°44'41.1" E 036°43'57.7" Alt. 699 mt.	Topsoil 20cm down from ground surface.
SAMPLE 5	N 14°44'55.3" E 036°44'24.4" Alt. 701 mt.	Topsoil 20cm down from ground surface.
SAMPLE 6	N 14°44'43.5" E 036°42'49.1" Alt. 696 mt.	Topsoil 20cm down from ground surface.

Coordinates and altitudes were taken using GPS unit with an approximation of ± 5 mt.

Soil tests results of Guluj samples

These are the result of the implemented analysis that identified sample n.5 as the best one for the earth blocks production.

Soil Sieve Analysis test on samples from Guluj

Sieves in mm	Guluj samples																Classification of grain size (ASTM-AFNOR)	Suitable grain size ratio (Habitat) %	
	Sieve analysis (washed) - passing and grain size content in %																		
	1		2		3		4		5		5 1m deep		5 2m deep		6				range (mm)
25.000	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	Pebbles	200 - 20	
19.000	100		100		100		100		99.5		100		100		100				
12.500	100		100		100		100		98.6		100		100		100				
9.500	100	0.1	100	0.1	100	0.1	99.5	6.5	98.2	7.1	100	2.6	100	6.1	100	1.7	Gravel	2- 20	15
4.750	100		99.9		100		98.5		97.2		100		100		100				
2.360	99.9		99.9		99.9		94.7		94.2		98.2		95.8		98.9				
2.000	99.9		99.9		99.9		93.5		92.9		97.4		93.9		98.3				
1.180	99.8		99.7		99.4		86.1		86.7		90.2		77.7		95.7				
0.600	99		98.5		97.5		70.8		72.1		68.2		38.1		90.3				
0.425	97.4	84	96.6	84	95.4	83	62.7	73	61.2	77	58.1	70	27.1	86	86.2	79	Sands	0.06 - 2	50-60
0.300	79.7		81.9		61.8		51.8		35		47.7		19.4		59.9				
0.150	38.8		27.3		27.7		30.5		21.5		34.7		11.8		31.4				
0.075	16.1		15.5		17.2		21		16.2		27.5		8		19.4				
over size %		16		16		17		21		16	1.8	28	4.2	8		19	Silts + Clays	< 0.06	35-45

Analysis implemented from 9/6/2001 to 15/6/2001 and from 10/7/2001 to 25/7/2001 (5 deep) by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

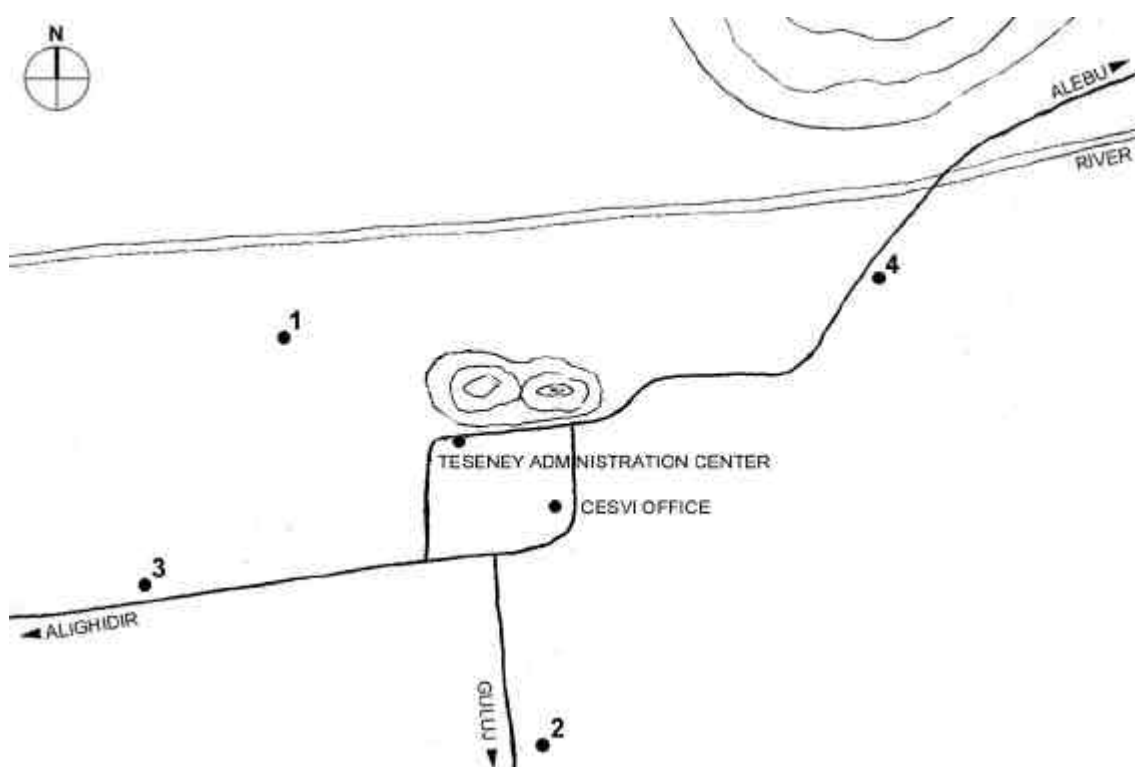
Soil Density and Liquid Limit Test on samples from Guluj

#	STD-PROCTOR:- MOISTURE DENSITY-RELATIONSHIP = DD/MC						MDD	OMC	L.L./P.I.	REMARKS
	1	2	3	4	5	6				
1.	1.56	1.6	1.665	1.7	1.66	1.6	1.7	10.2	N/P	SANDY-CLAY
	4.1	6.3	8.4	10.2	12.6	14.6				
2.	1.5	1.54	1.6	1.65	1.62	1.604	1.65	10.4	N/P	SANDY-CLAY
	4.4	6.4	8.2	10.4	12.2	14.4				
3.	1.5	1.53	1.64	1.71	1.66	1.616	1.71	11.6	N/P	SANDY-CLAY
	5	7	9.4	11.6	13	15.1				
4.	1.64	1.71	1.775	1.84	1.8	1.774	1.84	11	26/10	—
	5.3	7.4	9.2	11	13.3	15.6				
5.	1.645	1.72	1.81	1.92	1.866	1.806	1.92	10.2	25/6	—
	4.4	6.8	8.2	10.2	12.6	14.7				
5. 1m deep	1.65	1.7	1.75	1.85	1.8	1.825	1.85	11.2	36/15	NIL
	5	7.4	9.6	11.2	13.6	15.4				
5. 2m deep	1.625	1.71	1.754	1.81	1.775	1.7	1.81	8	N/P	SANDY
	3	4.4	6.2	8	10.1	12.4				
6.	1.445	1.51	1.56	1.62	1.6	1.544	1.62	13.3	25/8	—
	7.4	9.2	11.6	13.3	15.6	17.3				

Analysis implemented from 11/6/2001 to 16/6/2001 and from 10/7/2001 to 25/7/2001 (5 deep) by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

Tesenev Soil Map

As well as for Guluj we implement the same analysis on sample from Tesenev.



POINTS ON MAP	COORDINATES	NOTES
ADMINISTRATION CENTER	N 15°06'35.9" E 036°39'21.6" Alt. 615 mt.	Buildings of the administration as the town council.
CESVI OFFICE	N 15°06'26.6" E 036°39'41.1"	CESVI office in Tesenev
SAMPLE 1	N 15°06'58.2" E 036°38'49.6"	Soil 2 m down from ground surface.
SAMPLE 2	N 15°05'41.8" E 036°39'47.0"	Soil 1 mt down from ground surface. Already at this depth the soil is very compacted and hard to excavate.
SAMPLE 3	N 15°06'08.5" E 036°38'23.9"	Soil 1 mt down from ground surface. Already at this depth the soil is very compacted and hard to excavate.
SAMPLE 4	N 15°07'14.5" E 036°40'50.2"	Soil 50 cm down from ground surface. Already at this depth the soil is very compacted and hard to dig. Deeper soil doesn't seem to be different.

Coordinates and altitudes were taken using GPS unit with an approximation of ± 5 mt.

Soil tests results of Teseney samples

Soil Sieve Analysis test on samples from Teseney

Analysis implemented from 10/7/2001 to 25/7/2001 by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for

Sieves in mm	Teseney samples								Classification of grain size (ASTM-AFNOR)	range (mm)	Suitable grain size ratio (Habitat) %
	Sieve analysis (washed) - passing and grain size content in %										
	1		2		3		4				
25.000	100	0	100	0	100	0	100	0	Pebbles	200 - 20	0
19.000	100	0.3	100	0.5	100	1.1	100	2	Gravel	2- 20	15
12.500	100		100		100						
9.500	100		100		100						
4.750	100		100		100						
2.360	99.9		99.7		99.3						
2.000	99.7		99.5		98.9						
1.180	98.2	72.1	97.1	78.4	94.7	64.3	96.4	66.1	Sands	0.06 - 2	50-60
0.600	87.7		86.3		84.2		87.6				
0.425	75.2		76		77.6		80.2				
0.300	61.4		58		64.3		66.1				
0.150	39.7		33.3		44.2		42.9				
0.075	27.6		21.1		34.6		31.9				
over size %	0.1	27.6	0.3	21.1	0.7	34.6	1.7	31.9	Silts + Clays	< 0.06	35-45

Construction in Asmara - Eritrea.

Soil Density and Liquid Limit Test on samples from Guluj

#	STD-PROCTOR:- MOISTURE DENSITY-RELATIONSHIP = DD/MC						MDD T/M ³	OMC %	L.L./P.I.	REMARKS
	1	2	3	4	5	6				
1.	1.6	1.625	1.65	1.705	1.675	1.64	1.705	11.3	36/16	NIL
	5.3	7.2	9.2	11.3	13	15.1				
2.	1.505	1.52	1.555	1.575	1.55	1.5	1.575	7.8	32/14	NIL
	4.5	5.1	6.6	7.8	8.6	9.9				
3.	1.5	1.515	1.54	1.55	1.525	1.51	1.55	12.2	48/20	NIL
	6	8.2	10.4	12.2	14.4	16.4				
4.	1.49	1.52	1.55	1.6	1.575	1.54	1.6	13.4	40/18	NIL
	7	9.4	11.6	13.4	15	17.1				

Analysis implemented from 10/7/2001 to 25/7/2001 by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

THE ANALYSIS OF THE BLOCKS PRODUCED IN GULUJ

Earth blocks analysis of samples produced in the CESVI Block Factory in Gulu

Considering the results of the blocks made in Asmara and the analysis of the soil we decide to produce the following type of earth blocks with the soil sample n.5.

CEB have been produced with a manual press from Nairobi while the Adobes have been shaped with timber moulds. Here the results of the analysis implemented.

#	Type of block	Type of stabilization	Dimension of block (cm)	SSDB weight (Kg)	Entirely dry weight (Kg)	Entirely dry density (Kg/Mc)	Volume (Mc)	Moisture content (%)	Reading strength (KN)	One bed face area of the specimen (Sqm)	Dry strenght on surface unit (Mpa)
									Entirely dry		
1.	CEB	5% cement	29x14x11.5h	9.16	8.99	1,924	0.00467	1.97	244	0.041	6.0
2.	CEB	5% cement	29x14x11.5h	8.82	8.64	1,851	0.00467	2.1	204	0.041	5.0
3.	CEB	5% cement	29x14x11.5h	9.94	9.76	2,090	0.00467	1.9	204	0.041	5.0
4.	CEB	5% cement	29x14x11.5h	9.35	9.16	1,961	0.00467	2.13	200	0.041	4.9
5.	Adobe	5% cement	40x20x10h	15.41	15.03	1,879	0.00800	2.56	205	0.060	3.4
6.	Adobe	5% cement	40x20x10h	14.96	14.62	1,828	0.00800	2.28	200	0.060	3.3
7.	Adobe	5% cement	40x20x10h	14.64	14.38	1,798	0.00800	1.75	206	0.060	3.4

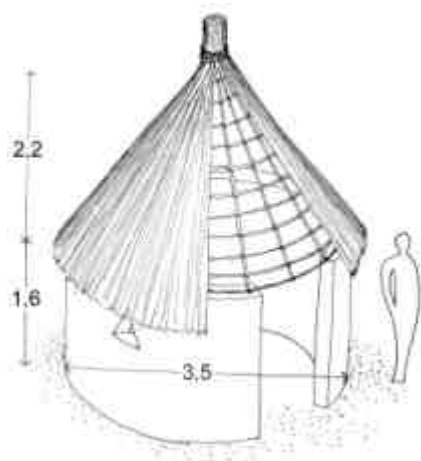
Analysis implemented from 10/7/2001 to 25/7/2001 by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

#	Type of block	Type of stabilization	Dimension of block (cm)	SSDB weight (Kg)	Entirely dry weight (Kg)	Entirely dry density (Kg/Mc)	Volume (Mc)	Moisture content (%)		Reading strength (KN)	One bed face area of the specimen (Sqm)	Wet strenght on surface unit (Mpa)
								D/T	1. M.S.	SSDB (Wet)		
1.	CEB	5% cement	29x14x11.5h	8.91	8.70	1,864	0.00467	2.4	3.0+	160	0.041	3.9
2.	CEB	5% cement	29x14x11.5h	8.84	8.60	1,841	0.00467	2.8	3.0+	150	0.041	3.7
3.	Adobe	5% cement	40x20x10h	13.48	13.16	1,645	0.00800	2.5	3.0+	120	0.060	2.0
4.	Adobe	5% cement	40x20x10h	13.62	13.31	1,664	0.00800	2.3	3.0+	110	0.060	1.8
5.	Adobe	straw fermented	40x20x10h	13.43	13.07	1,633	0.00800	2.8	3.5+	170	0.060	2.8
6.	Adobe	straw fermented	40x20x10h	13.10	12.74	1,593	0.00800	2.8	3.5+	180	0.060	3.0

Analysis implemented from 6/8/2001 to 9/8/2001 by senior-lab – Tech. Tesfai Zewde in AS.BE.CO. Central Laboratory for Construction in Asmara - Eritrea.

THE PROTOTYPES BUILT IN GULUJ

Traditional Tukul with thatched roof supported by timber structure



Floor area = 9.6 sqm
Covered area = 12 sqm



DESCRIPTION OF THE TRADITIONAL DWELLING

We analyse the traditional Tukul as a term of reference for the following prototypes.

Tukul or Agudò is the most used low-cost dwelling in the region and it is built from materials as soil, timber and straw. This traditional house doesn't have long durability and represent a not environmental friendly solution for the place because the use of timber.

Moreover walls and roof use to be attacked by termites that affect the durability of the structure and not less the timber structure of the roof is flammable representing a risk for fire accidents.

COST ANALYSIS

- Material 74.6 USD
- Labour 98.0 USD

Total	172.6 USD
Cost per built floor area (172.6 USD/ 9.6 sqm)	17.9 USD/sqm

Wall in ADOBE not stabilized and same mortar only cost of material (0 Nfa/vertical sqm)	no costs
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Roof in straw with timber structure cost of material (661 Nfa/12 sqm = 55 Nfa/sqm)	5.4 USD/sqm
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Traditional Tukul - cost of material

1.0 WALLS						
1.1	ADOBE not stabilized	dim.variable	av. 500 pcs	0.0 Nfa	0.0 Nfa	0.0%
Sub TOTAL				0.0 Nfa	0.0%	

2.0 ROOF						
2.1	Rafters	timber Ø av. 70mm	28.00 pcs	7.0 Nfa	196.0 Nfa	25.8%
2.2	Purlins	timber Ø av. 10mm	30.00 pcs	0.5 Nfa	15.0 Nfa	2.0%
2.3	Straw for roofing		300.00 bundle	1.5 Nfa	450.0 Nfa	59.1%
Sub TOTAL				661.0 Nfa	86.9%	

3.0 DOORS AND WINDOWS						
3.1	Door	90x1.60	1.00 pcs	100.0 Nfa	100.0 Nfa	13.1%
Sub TOTAL				100.0 Nfa	13.1%	

TOTAL				761.0 Nfa	100.0%	
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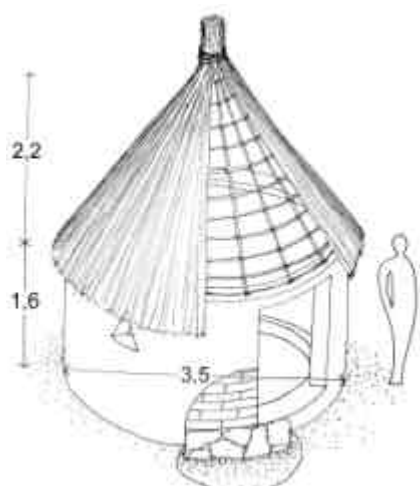
<u>Cost for one unit material</u>	* Exchange rate 1 USD = 10.2 Nakfa	74.6 USD
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Traditional Tukul - cost of labour

Super-structure. Walls and roof

• ADOBE av. 500 pcs	2 masons	1 labourers	2 days	300.0 Nfa
• Roofing				
Structure	2 masons	2 labourers	1.5 days	270.0 Nfa
Straw	by contract		2 days	250.0 Nfa
• Plastering work (external render)	2 masons	1 labourers	1 days	150.0 Nfa
• Door	1 masons		0.5 days	30.0 Nfa
Sub TOTAL			7 days	1,000.0 Nfa
TOTAL			7 days	1,000.0 Nfa
<u>Cost for one unit labour</u>		* Exchange rate 1 USD = 10.2 Nakfa		98.0 USD

Adobe improved Tukul with thatched roof supported by metal structure



Floor area = 9.6 sqm
Covered area = 12 sqm



PROTOTYPE DESCRIPTION

This proposal wants to be an intermediate technology answer for a very cheap and woodless construction dwelling. Originate from the traditional one it reproduce the local construction techniques for a Tukul improved in his durability (stone foundations, stabilized Adobe and mortar with 5% cement, reinforced concrete tie-beam) and in his safety thanks the metal structure resistant to fire.

Walls are protected by a proper plaster made of 2 coats: primer (2 lime, 1 sand, 1 soil) + external layer (1 lime, 1 sand) and they cannot be attacked by termites, as well as the roof, thanks to the foundations and the stabilized earth blocks.

COST ANALYSIS

- | | |
|------------|-----------|
| • Material | 238.5 USD |
| • Labour | 127.5 USD |

Total	366.0 USD
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Cost per floor area (366 USD/ 9.6 sqm)	38.1 USD/sqm
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Wall in ADOBE stabilized with 5% cement and stabilized soil mortar only cost of material (280.4 Nfa/17 sqm = 16.5 Nfa/vertical sqm)	1.6 USD/sqm
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Roof in straw with metal structure	
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cost of material (1330 Nfa/12 sqm = 110.8 Nfa/sqm)	10.9 USD/sqm
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Improved Tukul - cost of material

1.0 FOUNDATIONS						
1.1	Stones masonry foundation	-2 GL +.2, .4 with	1.96 mc	68.0 Nfa / mc	133.3 Nfa	5.5%
1.2	Cement mortar	cement, sand	0.30 mc	390.0 Nfa / mc	117.0 Nfa	4.8%
Sub TOTAL					250.3 Nfa	10.3%
2.0 WALLS						
2.1	ADOBE stabilized 5% cement	dim.40x20x10	425.00 pcs	0.6 Nfa	255.0 Nfa	10.5%
2.2	Mortar (soil + 5% cement)	sample 5 soil	0.17 mc	146.0 Nfa / mc	25.4 Nfa	1.0%
2.3	Concrete tie beam C-15	7 cm thick	0.18 mc	420.0 Nfa / mc	75.6 Nfa	3.1%
2.4	Iron bar	Ø 10mm	25.78 ml	2.5 Nfa / ml	64.5 Nfa	2.6%
2.5	Plastering outside (2 coats)	soil, sand, lime	17.00 sqm	10.0 Nfa / sqm	170.0 Nfa	7.0%
2.6	Painting with lime wash		17.00 sqm	9.5 Nfa / sqm	161.5 Nfa	6.6%
Sub TOTAL					752.0 Nfa	30.9%
3.0 ROOF						
3.1	Rafters	30 x 30 angle iron	63.00 ml	10.0 Nfa / ml	630.0 Nfa	25.9%
3.2	Purlins	Ø 10mm iron bar	78.00 ml	2.5 Nfa / ml	195.0 Nfa	8.0%
3.3	Straw for roofing		300.00 bundle	1.5 Nfa	450.0 Nfa	18.5%
3.4	Metal wire for binding		5.00 Kg	11.0 Nfa / Kg	55.0 Nfa	2.3%
Sub TOTAL					1,330.0 Nfa	54.7%
4.0 DOORS AND WINDOWS						
4.1	Door	90x1.60	1.00 pcs	100.0 Nfa	100.0 Nfa	4.1%
Sub TOTAL					100.0 Nfa	4.1%
TOTAL					2,432.2 Nfa	100.0%
Cost for one unit material					238.5 USD	
* Exchange rate 1 USD = 10.2 Nakfa						

Improved Tukul - cost of labour

Sub-structure. Foundations

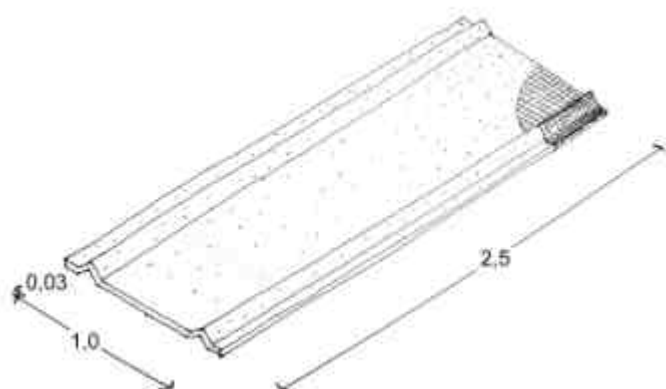
• Stone masonry work	2 masons	1 labourers	1 days	150.0 Nfa
Sub TOTAL			1 days	150.0 Nfa

Super-structure. Walls and roof

• ADOBE 500 pcs	2 masons	1 labourers	2 days	300.0 Nfa
• Tie-beam reinforced concrete				
Formwork + reinforcement	2 masons	1 labourers	1 days	150.0 Nfa
• Roofing				
Structure	2 masons	2 labourers	1.5 days	270.0 Nfa
Straw	by contract		2 days	250.0 Nfa
• Plastering work (external render)	2 masons	1 labourers	1 days	150.0 Nfa
• Door	1 masons		0.5 days	30.0 Nfa
Sub TOTAL			8 days	1,150.0 Nfa
TOTAL			9 days	1,300.0 Nfa

Cost for one unit labour				127.5 USD
* Exchange rate 1 USD = 10.2 Nakfa				

Ferro - Cement component for roofing



Covered area = 2.5 sqm

COMPONENTS DESCRIPTION

Cast with 3cm mortar 1:2 ratio with in between the reinforcement made of chicken mesh and iron bar this FC elements represent a woodless construction solution for roofing based on modern techniques.

EXPENSES FOR FC CHANNEL CASTING

- Material 19.3 USD
- Labour 14.7 USD

Total 34.0 USD

Cost per covered surface (34 USD/2.5 sqm) 13.6 USD/sqm

Roof in FC components only

cost of material (197.3 Nfa/2.5 sqm = 78.9 Nfa/sqm) 7.7 USD/sqm

FC channel for roofing - cost of material

Ferro-Cement channel (2.5x1x0.03 = 2.5 sqm)					
Chicken mesh 2 layers	2.5 x 1	5.00 sqm	20.0 Nfa / sqm	100.0 Nfa	50.7%
Iron bar	Ø 6mm	25.00 ml	1.8 Nfa / ml	45.0 Nfa	22.8%
Cement mortar 1:2	cement, sand	0.08 mc	654.0 Nfa / mc	52.3 Nfa	26.5%
TOTAL				197.3 Nfa	100.0%

Cost for one component material * Exchange rate 1 USD = 10.2 Nakfa **19.3 USD**

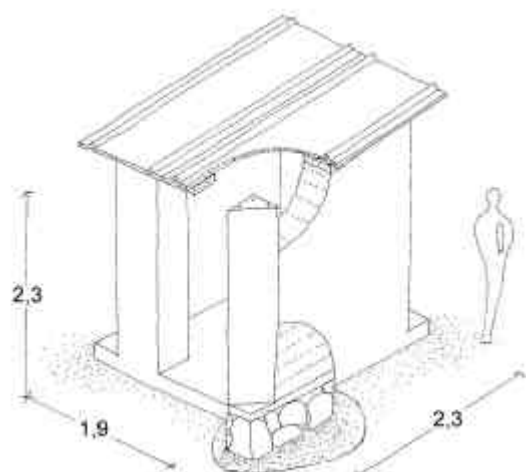
FC channel for roofing - cost of labour

Ferro-Cement channel (2.5x1x0.03 = 2.5 sqm)

• Casting work 2 masons 1 labourers 1 days 150.0 Nfa

Cost for one component labour * Exchange rate 1 USD = 10.2 Nakfa **14.7 USD**

Rammed Earth prototype with reinforced concrete structure and FC components for roofing



Floor area = 4.4 sqm
Covered area = 5 sqm



PROTOTYPE DESCRIPTION

This woodless construction proposal defines a very durable roofing and structure made in reinforced concrete that represent the skeleton in between which different walling solutions can be implemented.

For this prototype RE walling 30 cm thick has been provided on top of stone foundations.

Walls are protect with a proper plaster made of 2 coats: primer (2 lime, 1 sand, 1 soil) + external layer (1 lime, 1 sand).

As well as for the CEB prototype, the roofing solutions can be designed according to the room size in order to obtain overhang on all building sides.

Moreover the FC components roofing doesn't need any ceiling in order to stop the interior overheating thanks to the material composition.

COST ANALYSIS

- | | |
|------------|-----------|
| • Material | 199.7 USD |
| • Labour | 235.3 USD |

Total	435.0 USD
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Cost per floor area (435 USD/ 4.4 sqm)	98.9 USD/sqm
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Wall in RE 30 cm thick only cost of material	no costs
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Roof in FC components only	
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cost of material (394.6 Nfa/5 sqm = 78.9 Nfa/sqm)	
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	7.7 USD/sqm
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RE Prototype - cost of material

1.0 FOUNDATIONS						
1.1	Stones masonry foundation	0.4 deep, 0.4 with	1.09 mc	68.0 Nfa / mc	74.1 Nfa	3.6%
1.2	Cement mortar	cement, sand	0.04 mc	390.0 Nfa / mc	15.6 Nfa	0.8%
1.3	Metal mesh	as reinforcement	2.20 sqm	60.0 Nfa / sqm	132.0 Nfa	6.5%
1.4	Concrete grade beam C-15	10 cm thick	0.84 mc	420.0 Nfa / mc	352.8 Nfa	17.3%
Sub TOTAL					574.5 Nfa	28.2%
2.0 WALLS						
2.1	Concrete for columns C-15	dim. 30x30x42.4	0.41 mc	420.0 Nfa / mc	172.2 Nfa	8.5%
2.2	Iron bar, columns and tie beam	Ø 10mm	46.20 ml	2.5 Nfa / ml	115.5 Nfa	5.7%
2.3	Iron bar, columns and tie beam	Ø 6mm	48.38 ml	1.8 Nfa / ml	87.1 Nfa	4.3%
2.4	Concrete for tie beam C-15	10 cm thick	0.25 mc	420.0 Nfa / mc	105.0 Nfa	5.2%
2.5	Plastering outside (2 coats)	soil, sand, lime	12.20 sqm	10.0 Nfa / sqm	122.0 Nfa	6.0%
2.6	Painting with lime wash		12.20 sqm	9.5 Nfa / sqm	115.9 Nfa	5.7%
Sub TOTAL					717.7 Nfa	35.2%
3.0 ROOF						
3.1	Chicken mesh 2 layers	2.5 x 1	10.00 sqm	20.0 Nfa / sqm	200.0 Nfa	9.8%
3.2	Iron bar	Ø 6mm	50.00 ml	1.8 Nfa / ml	90.0 Nfa	4.4%
3.3	Cement mortar 1:2	cement, sand	0.16 mc	654.0 Nfa / mc	104.6 Nfa	5.1%
Sub TOTAL					394.6 Nfa	19.4%
4.0 DOORS AND WINDOWS						
4.1	Flat metal sheet door		1.00 pcs	200.0 Nfa	200.0 Nfa	9.8%
4.2	Flat metal sheet window		1.00 pcs	150.0 Nfa	150.0 Nfa	7.4%
Sub TOTAL					350.0 Nfa	17.2%
TOTAL					2,036.8 Nfa	100.0%

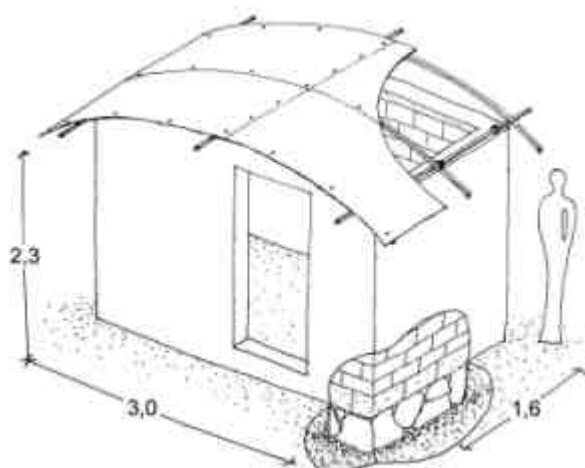
Cost for one unit material	* Exchange rate 1 USD = 10.2 Nakfa	199.7 USD
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RE Prototype - cost of labour

Sub-structure. Foundations				
• Stone masonry work	2 masons	1 labourers	1 days	150.0 Nfa
• Grade beam work	2 masons	1 labourers	1 days	150.0 Nfa
Sub TOTAL			2 days	300.0 Nfa
Super-structure. Walls and roof				
• Columns (formwork + reinforcement)	2 masons	1 labourers	3 days	450.0 Nfa
• Walling (formwork + ramming)	2 masons	1 labourers	6 days	900.0 Nfa
• Tie-beam (formwork + reinforcement)	2 masons	2 labourers	1 days	180.0 Nfa
• Roofing (casting of components)	2 masons	2 labourers	2 days	360.0 Nfa
• Plastering work (external render)	2 masons	1 labourers	1 days	150.0 Nfa
• Door and window	1 masons		1 days	60.0 Nfa
Sub TOTAL			14 days	2,100.0 Nfa
TOTAL			16 days	2,400.0 Nfa

Cost for one unit labour	* Exchange rate 1 USD = 10.2 Nakfa	235.3 USD
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Compressed Earth Block prototype with flat metal sheet roofing supported by metal structure



Floor area = 4.8 sqm
Covered area = 7 sqm

PROTOTYPE DESCRIPTION

This woodless construction is a proposal that mix local resources with new techniques of construction in order to define a low-cost house durable and environmental friendly.

Foundations are made with stone and supported by a row of CHB in order to protect the base of the walls from rain and termites

Above walling with CEB and stabilized mortar with 5% cement and reinforced concrete tie-beam have been provided. Walls are protect with a proper plaster made of 2 coats: primer (2 lime, 1 sand, 1 soil) + external layer (1 lime, 1 sand).

The roof, anchored to the tie beam, is made by a metal structure supporting galvanized flat metal sheets.

His design allowed the overhang on all building sides in order to protect the wall from the rain, and to facilitate a natural ventilation trough two opposite sides.

Moreover, the easy construction procedures can be performed on the ground to obtain a very light bofing solution that can cover also large span, according to the building design.

Mat ceiling tied-up with iron rod $\varnothing 6\text{mm}$ sewn on the edges has been provided to create a barrier between the room space and the roof.

To be notice that in comparison to the traditional CIS roofing with timber structure, this solution allowed the saving of some blocks because it doesn't need to be anchored to the walls with a supplementary row of blocks laid on the top of the sheets.

Moreover, it doesn't need to be lay on the top of vertical wall with different highness in order to create the necessary slope.

COST ANALYSIS

- | | |
|------------|-----------|
| • Material | 209.3 USD |
| • Labour | 120.6 USD |

Total	329.9 USD
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Cost per floor area (329.9 USD/ 4.8 sqm)	68.7 USD/sqm
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Wall in CEB stabilized with 5% cement and soil mortar stabilized only cost of material (378.9 Nfa/17.6 sqm = 21.5 Nfa/vertical sqm)	2.1 USD/sqm
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Roof in galvanized flat metal sheet with metal structure and mat ceiling cost of material (487.2 Nfa/7 sqm = 69.6 Nfa/sqm)	6.8 USD/sqm
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CEB Prototype - cost of material

1.0 FOUNDATIONS						
1.1	Stones masonry foundation	0.4 deep, 0.4 with	1.30 mc	68.0 Nfa / mc	88.4 Nfa	4.1%
1.2	Cement mortar	cement, sand	0.30 mc	390.0 Nfa / mc	117.0 Nfa	5.5%
1.3	CHB	0.2 above GL	21.00 pcs	4.0 Nfa	84.0 Nfa	3.9%
1.4	Metal mesh	as reinforcement	1.68 sqm	60.0 Nfa / sqm	100.8 Nfa	4.7%
1.5	Concrete grade beam C-15	5 cm thick	0.08 mc	420.0 Nfa / mc	33.6 Nfa	1.6%
Sub TOTAL					423.8 Nfa	19.8%
2.0 WALLS						
2.1	CEB stabilized 5% cement	dim. 29x14x11.5	510.00 pcs	0.7 Nfa	357.0 Nfa	16.7%
2.2	Mortar (soil + 5% cement)	sample 5 soil	0.15 mc	146.0 Nfa / mc	21.9 Nfa	1.0%
2.3	Concrete tie beam C-15	10 cm thick	0.16 mc	420.0 Nfa / mc	67.2 Nfa	3.1%
2.4	Iron bar	Ø 10mm	25.20 ml	2.5 Nfa / ml	63.0 Nfa	3.0%
2.5	Iron bar	Ø 6mm	12.00 ml	1.8 Nfa / ml	21.6 Nfa	1.0%
2.6	Plastering outside (2 coats)	soil, sand, lime	17.62 sqm	10.0 Nfa / sqm	176.2 Nfa	8.3%
2.7	Painting with lime wash		17.62 sqm	9.5 Nfa / sqm	167.4 Nfa	7.8%
Sub TOTAL					874.3 Nfa	40.9%
3.0 ROOF						
3.1	Rafters and purlins	20 x 20 RHS	17.40 ml	8.0 Nfa / ml	139.2 Nfa	6.5%
3.2	Galvanized flat sheet	2 x 1	4.00 pcs	75.0 Nfa	300.0 Nfa	14.0%
3.3	Bolts, nuts and washers	different sizes			30.0 Nfa	1.4%
3.4	Mat ceiling	1.3 x 2.7	1.00 pcs	18.0 Nfa	18.0 Nfa	0.8%
Sub TOTAL					487.2 Nfa	22.8%
4.0 DOORS AND WINDOWS						
4.1	Metal frame door		1.00 pcs	200.0 Nfa	200.0 Nfa	9.4%
4.2	Metal frame window		1.00 pcs	150.0 Nfa	150.0 Nfa	7.0%
Sub TOTAL					350.0 Nfa	16.4%
TOTAL					2,135.3 Nfa	100.0%
Cost for one unit material					* Exchange rate 1 USD = 10.2 Nakfa	
					209.3 USD	

CEB Prototype - cost of labour

Sub-structure. Foundations

• Stone masonry work	2 masons	1 labourers	1 days	150.0 Nfa
• CHB and reinforced concrete 5cm thick	2 masons	1 labourers	1 days	150.0 Nfa
Sub TOTAL			2 days	300.0 Nfa

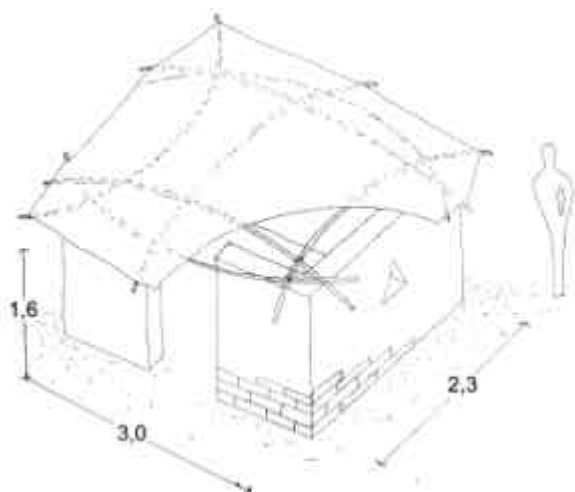
Super-structure. Walls and roof

• Laying of CEB 495 pcs	2 masons	2 labourers	2 days	360.0 Nfa
• Tie-beam reinforced concrete Formwork + reinforcement	2 masons	2 labourers	1 days	180.0 Nfa
• Roofing RHS and metal sheet bolted	2 masons	2 labourers	1 days	180.0 Nfa
• Plastering work (external render)	2 masons	1 labourers	1 days	150.0 Nfa
• Door and window	1 masons		1 days	60.0 Nfa
Sub TOTAL			6 days	930.0 Nfa
TOTAL			8 days	1,230.0 Nfa

Cost for one unit labour

* Exchange rate 1 USD = 10.2 Nakfa

120.6 USD



Floor area = 6.9 sqm
Covered area = 14 sqm



PROTOTYPE DESCRIPTION

This semi-permanent shelter is a proposal for IDPs, refugees etc. camps that receive the metal structure and the plastic sheeting for a temporary dwelling.

The technology proposed for the walls is based on Adobe stabilized with straw. A non-durable solution but a very well known technique of construction that doesn't need any investment from the beneficiaries because the composition of the blocks.

Therefore a no added cost solution for a dwelling that can represent a more comfortable place where to live for a short time thanks to the ventilation available through the lateral windows and the good insulation because the earth walls.

The roof structure is made by the curved metal pipes tied together and anchored to the wall thanks metal wire.

On the top of that the plastic sheeting represent, with overhang on all sides, the protection from the rain and the sun.

GENERAL CONCLUSION

Results of the research on materials and roofing solutions

Far to give any definitive conclusion on the use of earth technologies for housing construction in Gash-Barka we believe that other research must be implemented in order to find the suitable answer that can combine a “strong wall” to a “good design” for a sustainable, durable and comfortable dwelling.

In fact, because earth blocks are sensitive to the influence of the water, the answer about the full use of these technologies will come only after some rain season.

Different kind of plaster must be tested and other housing design must be implemented to find the suitable combination.

Anyway, we already identified some possible material for construction as the CEB and the Adobes that result very strong to carry a one floor building.

A comparison with the other well-know technology used for housing construction, as the CHB, put in evidence the more

Table of comparison between earth blocks and CHB produced in Guluj and other masonry material.	Dimension	Performances				
	cm	Wet compressive strenght Mpa	Density Kg/mc	Reversible thermal dilation %	Thermal insulation W/m°C	Durability
CHB - Concrete Hollow blocks ratio 1:4	40x20x20h	0.7 to 5 1.9	1700 to 2200 1875	0.02 to 0.05	1.0 to 1.7	low to very good
CEB - Compressed Earth Block stabilized with 5% cement	29x13x11.5h	1 to 4 3.8	1700 to 2200 1850	0.02 to 0.2	0.81 to 1.04	low to very good
ADOBE stabilized with 5% cement	40x20x10h	0 to 5 1.9	1200 to 1700 1650	-	0.4 to 0.8	poor
stabilized with straw fermented	40x20x10h	2.9	1610			
Fired Bricks		0.5 to 6	1400 to 2400	0 to 0.02	0.7 to 1.3	low to excellent

Font of general datas: Vincent Rigassi – Compressed earth blocks. Volume I. Manual of production – Vieweg 1995

sustainable answer represent by earth blocks, first of all because they reflect the local culture and secondly because they are based on the use of local resources...

General principles of sustainability of examined material and techniques of construction for Guluj area.	Financial sustainability Cost of material only	Environmental sustainability Availability of indigenous building materials	Technical sustainability Reflection on local technical solutions and availability of local skillsbase and machinery	Cultural and social sustainability Reflection of local culture, customs and way of life
WALLING				
CHB 1:4 ratio	5.1 USD/sqm	needs cement	Already known technique. Need of eletric machinery	Well-known by locals that can afford it.
CEB 5% cement	2.1 USD/sqm	needs cement	Easy technique. Need manual machinery	Well-known but not appreciate.
Adobe 5% cement	1.6 USD/sqm	needs cement	Traditional technique. No machinery need.	Traditional technique.
Adobe with straw	no costs	all available	Traditional technique. No machinery need.	Traditional technique.
RE soil only	no costs	all available	Non traditional technique. No machinery need.	Unknown. No previous experiences
ROOFING				
CIS timber structure	8.4 USD/sqm	needs all	Well-known technique by expert masons	Well-known by locals that can afford it.
Flat Iron Sheet metal structure	6.8 USD/sqm	needs all	Unknown technique	Unknown. No previous experiences
FC components	7.7 USD/sqm	needs all except sand	Unknown technique	Unknown. No previous experiences
Thached roof with metal structure	10.9 USD/sqm	needs metal structure	Well-known technique by locals	Based on traditional technique.
Thached roof with timber structure	5.4 USD/sqm	needs timber structure	Well-known technique by locals	Traditional technique.

Categories of sustainability from: E. Lopez M., R. Nordberg UNCHS - Programme for Emergency and Rehabilitation in War-Affected Areas in Eritrea - October 2000

The roofing solution investigated are based on different approaches:

- The intermediate technology, here represented by the improved thatched roof
- The new components solution, here represented by FC channel
- The new solution based on the use of already used endogenous materials, here represented by the FIS roofing

The thatched roof with metal structure is a proposal that combine the local techniques of construction, and the good climatic answer represents by the use of the straw, with a woodless solution.

The final analysis put in evidence the high cost of this roofing also if it can be a proper solution because the local implementing procedures.

The Ferro–Cement components solution is based on imported materials and needs skilled masons to be cast.

Moreover the weight of these elements must be considered for a long span roof that oblige to a not-easy design of this channels.

Anyway this solution could be a durable and comfortable solution for hot climate area where metal sheets seems to represent the only alternative answer to the thatched roof.

The Flat Iron Sheet solution is another wood less construction roof that represents a innovation for Gash-Barka. The affordable price, the appropriate design for earth dwellings, could represent a good alternative to the traditional CIS system.

These result intend to represent a starting point for a further research that will analyses not just the materials of construction, but also the design of the house in relation with the customs, the social habits and the traditions of Guluj or more in general of the low-land areas of Eritrea.

