www.a-4-a.org

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The University Of Sheffield.

Read the project blog at www.01liveproject07.wordpress.com

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executive summary

1. UNHCR, '2006 Global Trends: Refugees, Asylum Seekers, Returnees, Internally Displaced Persons and Stateless Persons', Division of Operational Services, Field Information and Coordination Support Section, http://www.unhcr.org/statistics/STATISTICS/4676a71d4.pdf, 2006

In refugee camps across the globe there is a deep concern as to the viability of using (short term) temporary shelter such as tents. Many of the 23,700,000 internally displaced persons (IDPs), in around 49 different countries, are expected to stay in these camps for several years[1].

In some regions more long term alternatives present themselves readily. In dry and arid environments mud bricks are often the only available resource due to a simple lack of any other building material. Mud brick manufacture in arid environments brings with it the inherent problem of the supply of water.

Architects for Aid approached us with an idea: why not use human urine instead of water?

Animal urine and dung has been used in building for years. Human urine has been used in fertilizer. So the premise seems fine but what are the implications?

Much research already exists into the manufacture of mud bricks. However, there has been no research that we are aware of that looks into the use of urine in mud brick making.

By standardising our test soils dry components and varying only the liquid fraction in proportion and composition (water, urine and 50/50 mix) we could determine whether bricks made with urine perform as well as those made with water. This enabled us to carry out comparative tests for crushing strength and secondary qualitative tests for resistance to abrasion, sprayed water and soaking.

In general the experiments demonstrated the soundness of using urine as a substitute for water, at least in the short term. The results of the crush test clearly show that urine does not weaken mud bricks and, if anything, our qualitative tests suggest it actually enhances the physical properties.

Based on the principle that human urine can be used in mud bricks in arid regions; we speculated on what issues would need to be addressed to make the implementation of such a scheme viable. The research undertaken highlighted several major issues including collection, storage, sterilisation, and methods of use.

The conclusion from all our research is that urine is a viable alternative to water in mud brick shelters for refugee camps. Just as, if not more importantly, the test results imply that the traditional boundaries of use for mudbrick buildings can be expanded with the use of urine due to the increased resistance to water damage, the main weakness of mudbrick.

foreword by Jack Pringle

I am delighted to introduce this report on the feasibility of using human urine in mud brick construction. This is an area of research that has a potentially significant impact in areas such as Darfur, where there is a desperate need for semi-permanent shelter, but water, an increasingly precious commodity for human survival, is in short supply and not available for making mud bricks.

The research done by the University of Sheffield's School of Architecture on behalf of Architects for Aid is a first in the field. It provides important insights into this method of construction and exactly the sort of brilliant, but simple, innovation that can resolve what appears to be an intractable problem, providing a simple, local and sustainable solution.

The report is exemplary of the ethos of Architects for Aid, using architectural intelligence to help and empower people who would not otherwise have access to design and research input.

I would particularly like to thank the Sheffield students for their energy, commitment and rigour in completing this ingenious research. They should take great satisfaction from the thought that their work may be truly useful in the field.

I hope that this is the first of many such collaborations between A4A and University departments.

Jack Pringle

Trustee, Architects for Aid

Past president, Royal Institute of British Architects

foreword by Michael Ferreira

Michael Ferreira

Head of Field Operations,
Architects for Aid

Registered Charity No. 1112621

Architects for Aid
http://www.A-4-A.org/

At the Shelter Conference 07a, in May of 2007, Gerd Ludekind of UN-HABITAT made presentation on some of the issues surrounding the reconstruction of housing stock in Darfur.

One result of the conflict was that a lot of villages had been burnt to the ground and would require about 16 million trees to rebuild them. According to Gerd there are not 9 million trees in the region, not to mention that mud brick building is made difficult as water is extremely scarce and invariably needed for drinking. He advocated looking for other ways to help in the reconstruction effort. During the presentation, the CEO of A4A, Dr Victoria Harris, had an idea: "Why not use the urine instead of water to build with?"

This was the idea that led us to investigate human urine as a possible replacement for water in mud brick construction.

To carry out the initial background testing of the idea we have teamed up with the final year students of Sheffield University on one of their well known Live Projects.

Animal urine and dung has been used in building for years because urea is known to be an effective binding agent. Human urine has been used as fertilizer. So the premise is fine but how much urine does it take to build a brick? How many bricks can you use to build a house for a refugee? How strong are the bricks? What kind of production line can you set up at a refugee camp? This is what we asked the students to find out.

foreword by Jeremy Till

I am proud to introduce this work from the School of Architecture at the University of Sheffield. The project forms part of our now renowned 'Live Projects' programme, in which our postgraduate students spend five weeks working on a wide variety of projects, all of them with real clients and with real outputs whether buildings, websites, strategic plans or reports such as this.

The aim is to open up the School of Architecture to people and organisations who would otherwise not have access to the research, energy, design sense and intelligence of a leading University. It also fits the School's mission in developing an understanding of the social responsibility of the architect and architectural student. So what, you may ask, are architecture students doing researching mud bricks and urine? Shouldn't they be designing buildings?

The answer to the latter is, of course, yes, and they should be brilliantly designed; but they should not be the sole objects of architectural attention. Architectural education exposes students to a huge range of methods and ways of thinking, and the febrile intelligence that this develops can be applied to much more than buildings as objects.

This report in bringing together the sciences and social sciences, practicality and theory, the human with the technical, scholarly research and informed hunch, shows exactly the strength of architectural education and the way that it can be deployed in an empowering manner. I think the authors have done fantastically to get this far in such a short space of time, and hope that others find it useful.

Professor Jeremy Till

Director of Architecture

The University of Sheffield, School of Architecture

acknowledgements

We would like to offer our collective thanks to all those who contributed in any way to this project, through discussion, gracious donations (!) or spirit.

In particular we would like to thank the following, without whom this research project may have remained hopelessly absurd:

Gregory Barrow from the World Food Programme.

The technicians, in the Department of Civil and Structural Engineering at The University of Sheffield, for their generously donated time and equipment.

Professor Tony Parsons, Professor of Sediment Systems in the Department of Geography at the University of Sheffield, who supplied us with vital information regarding soil / clay construction and who, conveniently, worked at the University of Khartoum (1973-4).

Jeremy Till, Professor of Architecture and Director of Architectural Studies at the University of Sheffield, who acted as mentor and motivator.

Professor Ian Burgess, Professor of Structural Engineering, Head of Civil and Structural Engineering Department for allowing us to carry out crush tests in the engineering department.

Glenn Brawn, Laboratory Superintendent, Civil and Structural Engineering Department for letting us into the engineering lab and advising us on crush tests.

Paul Blackbourn, Senior Technician of Materials and Structures Laboratories, Department of Civil and Structural Engineering for advising us on lab procedure and safety, and carrying out crush tests.

Dr Sally L McArthur, Senior Lecturer in Biomedical Engineering, Course Director for Biomedical Engineering, Department of Engineering Materials for advice at early stages of research into interactions between urine and clays.

Dr Neil B Milestone, Senior Lecturer, Department of Engineering Materials for advice into interactions between urine and clays.

Paul Osborne, Laboratory Supervisor at Geotechnical and Water Engineering Laboratories, Civil and Structural Engineering Department for advice on possible tests for moisture content of soils.

Dr Charles Hird, Reader, Civil and Strutural Engineering Department for general advice on properties of clays and possible moisture content tests.

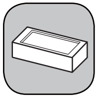
Dr M Wainwright, Microbiologist, Molecular Biology and Biotechnology Department at The University of Sheffield for information about urine, in particular, on health issues and methods of sanitisation.

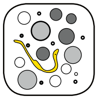
We have made every attempt to identify, accurately, the sources and authors of all photographs, images and quotations. If any thing has been omitted we would be happy to address the situation.

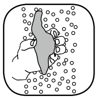
key to icons

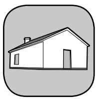
 vegetation

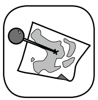
 academic consultation

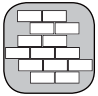
 mud bricks

 soil

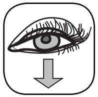
 clay

 shelter

 locality

 construction

 process

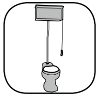
 observations

 experiments

 strengths

 social

 safety

 collection

 internet research

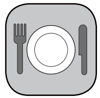
 hazard / danger

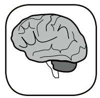
water

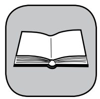
 positive

 negative

 urine

 diet

 learning

 written research

 health

contents

"The greatest humanitarian challenge we face today is that of providing shelter."

Architecture for Humanity, Design Like You Give a Damn, 2006.

introduction

the brief

We were approached by Architects for Aid with the aim of testing the plausibility of using human urine in mud brick construction. It was clear the investigation needed to be dealt with in two parts. Firstly, taking the question: can human urine be used as an agent in the manufacture of mud bricks? as a starting point, we assessed the viability through actual experiments and observations; comparing and contrasting the processes and actual bricks made with human urine and water. Secondly, based on the principle that human urine can be used in mud brick manufacture in arid regions, we speculated on what issues would need to be addressed to make the implementation of such a scheme viable.

This report hopes to serve as a compendium of the research undertaken by the Live Project 07: Mud Brick Shelter group. The intention was never to provide a complete statement on using human urine in mud brick production but to pose as many questions as we answered; to highlight issues (social, environmental, practical, epidemiological etc) and perhaps suggest appropriate models and methods for their resolution. Based on our observations and experiments we hope to make the strongest, practical, most socially useful, inferences possible.

Visit the group blog at: http://01liveproject07.wordpress.com/

Currently there are 23,700,000 internally displaced persons (IDPs) in at least 49 countries[2] and over half the worlds population, more than 3,000,000,000 people, lack access to clean water or proper sanitation facilities[3]. In arid regions of the world in particular, many of the resources necessary to provide and rebuild shelter for IDPs are simply unavailable.

2. United Nations High Commissioner for Refugees, Refugees by Numbers - 2006 edition Available at http://www.unhcr.org/cgi-bin/texis/vtx/basics/opendoc.htm?tbl=BASICS&id=3b028097c#Refugees

3. Alexander, Zehnder, Schertenleib, Water issues: the need for action at different levels, 'Aquatic Sciences, Research Across Boundaries', Volume 65, Number 1, March, 2003

“We used to go through a place on our way from the Himalayas to Delhi, where we had to wait for a train. There were beautiful mud houses, but the soil was totally unsuitable. So I tried to find out what the stabilizer was that they used. But they would not tell me! What was this nosy blighter from outside wanting to know this for? Eventually I discovered that they were using pig’s urine! We chased pigs and got their urine analyzed. The urea content is very high, and urea is a binder.”[4]

4. Hochschild, Mother Jones Magazine, July/August, 2000

5. Baker, Alternative building materials: timeless mud. in, Architecture & design, vol. 3, no. 3, Mar/Apr, pp. 32-35, 1987

The source that started this exploration into the use of human urine in mud brick making was a series of publications by the late Laurie Baker, a celebrated architect in India, who explored the use of local techniques and simple materials in the making of beautiful architecture sensitive to both client and context.

Investigating this mention of urine use, however, has proved frustrating. Though it has been mentioned on several occasions, and always by Baker himself, it is impossible to verify details he mentions or even know precisely what area of India he is talking about. Therefore, important details about the use of pig’s urine, such as whether it was putrefied and whether it was the sole additive to the mud-bricks, remain unknown to us.

The most intriguing part of what Baker says in this passage is that the soil would not normally be suitable for making mud bricks but that using the urine enabled the villagers not just to make mud bricks but to make them very well with “…no cracks although the buildings were very old.”[5] The implications of this, if it is indeed the case, is to open up the possibility of medium to long-term accommodation in areas of the world where this would only be possible using more expensive materials. For a refugee in an arid area without access to these alternatives this factor could be of fundamental importance.

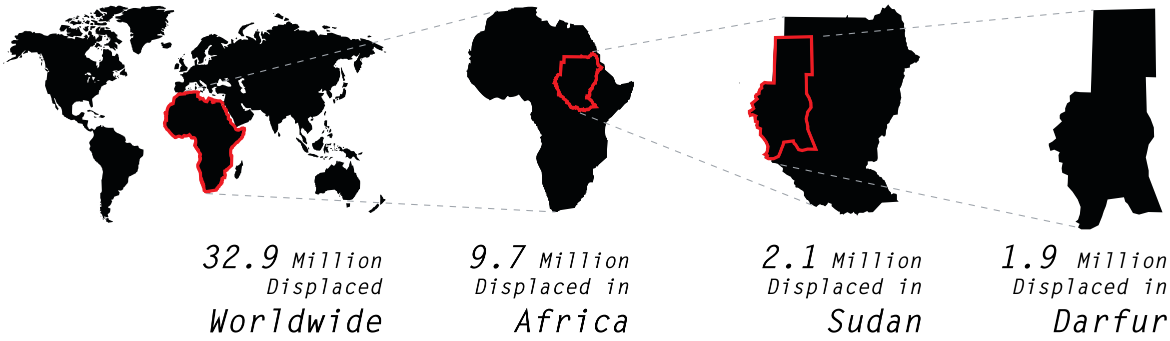
“Worldwide, the displaced population was estimated at 32.9 million migrants at the end of 2006”

UNHCR Global Change Document 2006

displacement figures

at the end of 2006

Displaced persons including refugees, asylum seekers, returnees, IDPs and stateless persons



Displacement Figures Diagram Information Source: UNHCR Global Change Document (for Worldwide, Africa and Sudan) United Nations Office for the Coordination of Humanitarian Affairs Affected Populations document (for Darfur), 2006

displacement issues: global

The ever growing problem of global displacement has led to vast increases in requirements for transitional and semi-permanent shelters. With a worldwide displaced population of 32.9 million migrants at the end of 2006[6], the provision of adequate shelter is a very real issue.

A development from transitional shelters to semi-permanent structures is a hugely important sociological issue for refugees and IDP populations. A large percentage of the displaced populations have experienced varying degrees of trauma or are in the process of grieving. According to a study conducted on Cambodian refugees by the United States National Institute of Mental Health, 62% of those surveyed had suffered Post-Traumatic Stress Disorder, 51% had experienced 'major' depression and 90% had a family member or friend murdered[7]. These statistics highlight the need for stability and security in refugee and IDP camps.

This live project is specifically based on the need for semi-permanent accommodation for migrants in dry, arid environments. The need to substitute water with urine as a binding agent for mud bricks is likely to be only relevant to these conditions, particularly to the Darfur region and Darfur / Chad border because of the current conflict. However, we hope that the information in this project will be relevant to any arid region in which there are displaced populations.

6. UNHCR, 'UNHCR Global Change Document', UNHCR http://www.unhcr.org/publ/PUBL/4444afce0.pdf, 2006

7. PTSD, Depression Epidemic among Cambodian Immigrants, http://www.nimh.nih.gov/science-news/2005/ptsd-depression-epidemic-among-cambodian-immigrants.shtml

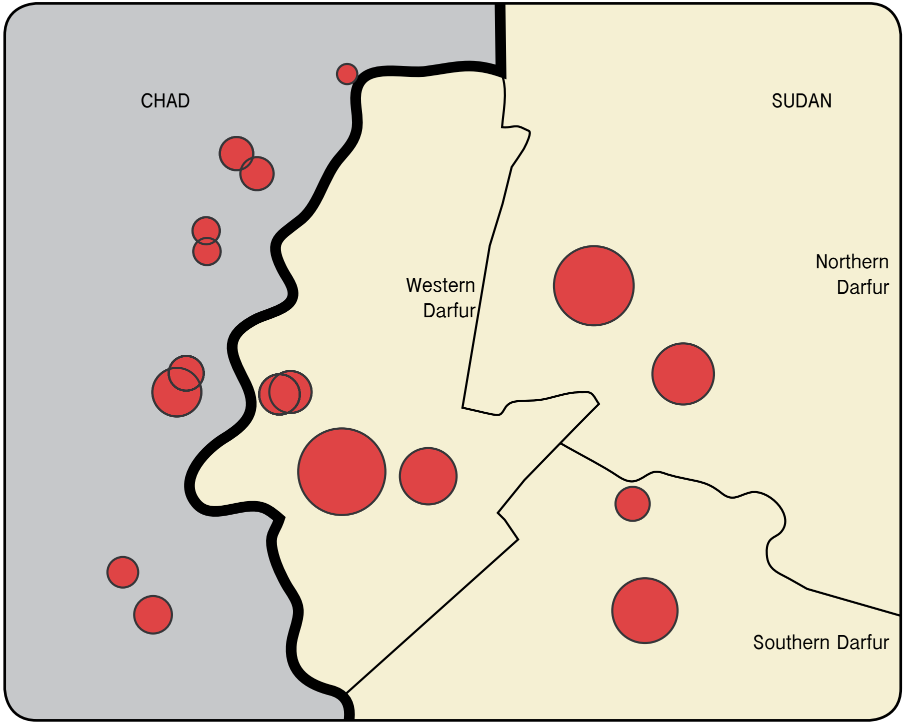
Imagez, +Scorthed Earth Policy http://www.natcreole.com/may.issue/features/darfur.fire.jpg

Image Brian Steidle, 'The Devil Came on Horseback: Bearing Witness to the Genocide in Darfur, New York, Public Affairs, 2007

map of refugee and IDP camp sizes

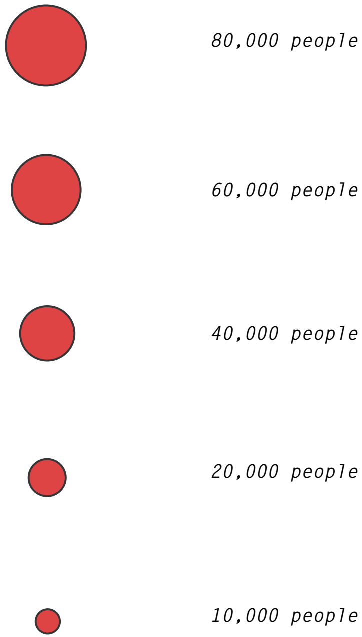
in Darfur and the Sudan / Chad border

Sudan has the fourth largest population of concern identified by the UNHCR (after Afghanistan, Columbia and Iraq).[8]



Map of Refugee and IDP Camp sizes
Information Source: http://www.usaid.gov/locations/sub-saharan_africa/countries/sudan/images/satellite/index.html

Refugee / IDP Camp Approximate Populations:



Sudan's complex and problematic history has consisted of a number of civil wars and severe famines and droughts. The current Darfur conflict is a result of tensions between ethnic groups, fundamentally heightened by vast water shortages and perceived government favouritism[9]. The government has responded to uprisings brutally, fronted by the Janjaweed militia who mass-murdered communities, burned villages, poisoned wells and killed animals practicing a scorched-earth policy to stamp out rebel uprisings[10]. UN Under Secretary General for Humanitarian Affairs, Jan Egeland, described the Darfur conflict as "the world's worst humanitarian disaster".[11]

The refugees and IDPs that have resulted from the conflict are almost entirely dependant on humanitarian aid and have little to no chance of returning to their homes in the foreseeable future. It has highlighted how difficult it is to protect internally displaced persons when their own government has caused the displacement and fails to comply with UN resolutions to provide security[12]. Since the early 1980's Sudan has been repeatedly amongst the top three most heavily indebted countries in sub-Saharan Africa[13].

The combination of a number of interwoven issues has led to the present conflict which has left huge vunerable populations in need of shelter.

8. UNHCR, '2006 Global Trends: Refugees, Asylum Seekers, Returnees, Internally Displaced Persons and Stateless Persons', Division of Operational Services, Field Information and Coordination Support Section, http://www.unhcr.org/statistics/STATISTICS/4676a71d4.pdf, 2006

9. UNHCR, 'The Sate of the World's Refugees', http://www.unhcr.org/cgi-bin/texis/vtx/template?page=publ&src=static/sowr2006/toceng.htm, 2006

10. UNHCR, ibid

11. UNHCR, ibid

12. UNHCR, ibid

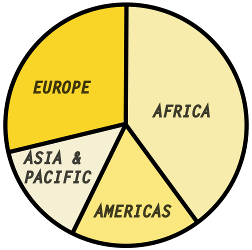
13. Adar, 'Sudan: The Internal and External Contexts of Conflict and Conflict Resolution', Department of Political Studies/International Studies Unit, Rhodes University, South Africa, UNHCR Centre for Documentation and Research http://www.unhcr.org/publ/RSDCOI/3ae6a6ca8.pdf, 2000

refugee camp in darfur

*Panoramic Photograph,
http://www.worldvision.org/
worldvision/appeals.nsf/stable/
darfur_panoramic*

refugee camp conditions

Chart of Worldwide Refugee Populations:



populations(refugees only) at the end of 2006 by UNHCR region

The displacement of approximately 1.9 million people in Sudan[14] has resulted in the emergence of makeshift camps and vastly overpopulated villages in the Darfur region, and approximately 200,000 refugees in 12 camps in neighbouring Chad set up by the UNHCR[15].

With the conflict in its fifth year, the camps are beginning to grow in permanence, the sticks and plastic sheeting shelters are being replaced by mud brick dwellings. However, the hardships faced by the displaced are worsened by the conditions within the camps, not to mention the virtual absence of access to education and economic opportunity. 90% of the Sudanese population lives below the poverty line.

Food:

There are vast food shortages in Sudan as a result of drought and years of conflict. It is estimated that 180,000 have died of starvation due to the conflict[16]. In 2007, some 2.8 million people in Sudan are expected to require food assistance[17].

The World Food Programme standard ration is 2100 kcals per day, but this has been halved in Darfur due to emergency food shortages[18]. The rations are largely cereal based and supplemented by foods such as dried pulses and vegetable oils.

14. UNHCR Standing committee Note on International Protection, 7th June, 2005, p.2

15. UNHCR Chad/Darfur Emergency website www.unhcr.org/chad.html. 2007

16. United Nations Development Programme 'Gender and Citizenship Initiative Country Profile: Sudan' http://gender.pogar.org/countries/country.asp?cid=18, 2007

17. World Food Programme, 'Where We Work: Sudan', http://www.wfp.org/country_brief/indexcountry.asp?region=9&section=9&sub_section=9&country=736, 2007

18. Consultation with Gregory Barrow, World Food Program, 12.10.07

Refugee Populations by UNHCR Regions
Information Source: UNHCR 2006 Global Change Document

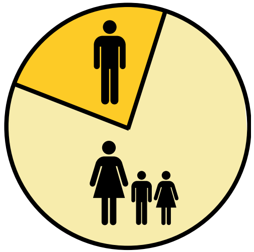
refugee camp population percentages

in the Sudan region

1. Ratio of Urban, Rural and Refugee / IDP camp populations

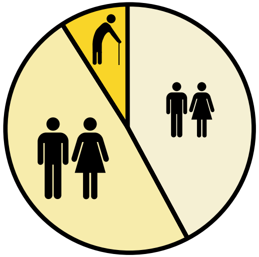
Total Sudanese population

2. Ratio of Male to Women and Children in refugee/ IDP camps



Kounoungo refugee camp, Darfur

3. Percentages of under 18's, 18-59 year olds and over 60's



Wad Sherife, Sudan

Refugee Camp Popualtion Percentages
1. 2. & 3. UNHCR, 'UNHCR Global Change Document', UNHCR http://www.unhcr.org/publ/PUBL/4444afce0.pdf, 2006

Arial photograph of the Kassab Camp, Kutum, North Darfur http://www.thewe.cc/contents/more/archive/darfur_sudan.html

One of the Darfur regions largest IDP camps with a population of over 70,000 inhabitants Image: Brian Steidle, 'The Devil Came on Horseback: Bearing Witness to the Genocide in Darfur, New York, Public Affairs, 2007

Water:

The Sudanese water crisis has been brought about by both drought and the practical difficulties in installing and fixing water wells. With swollen populations in the Darfur and Chad border surviving on the same number of water access points, lack of sufficient water has been a major factor in the deterioration of living conditions within the refugee camps. In some of the refugee camps in Chad, that have no water source at all, water rations are at half the international standard for emergency situations[19]. Water shortages are likely to worsen in the future due to the increase in mud brick construction, as described by Oxfam. "A surge in building homes from mud bricks has eased a housing shortage, but accelerated a water shortage in western Sudan."[20]

Timber:

Scarce timber resources are also a source of tension on the overpopulated camps. The arid conditions of the region combined with Sudan's history of drought, means that the supply of wood for building and cooking is very limited. This has been worsened by the use of timber for temporary shelter in refugee camps.

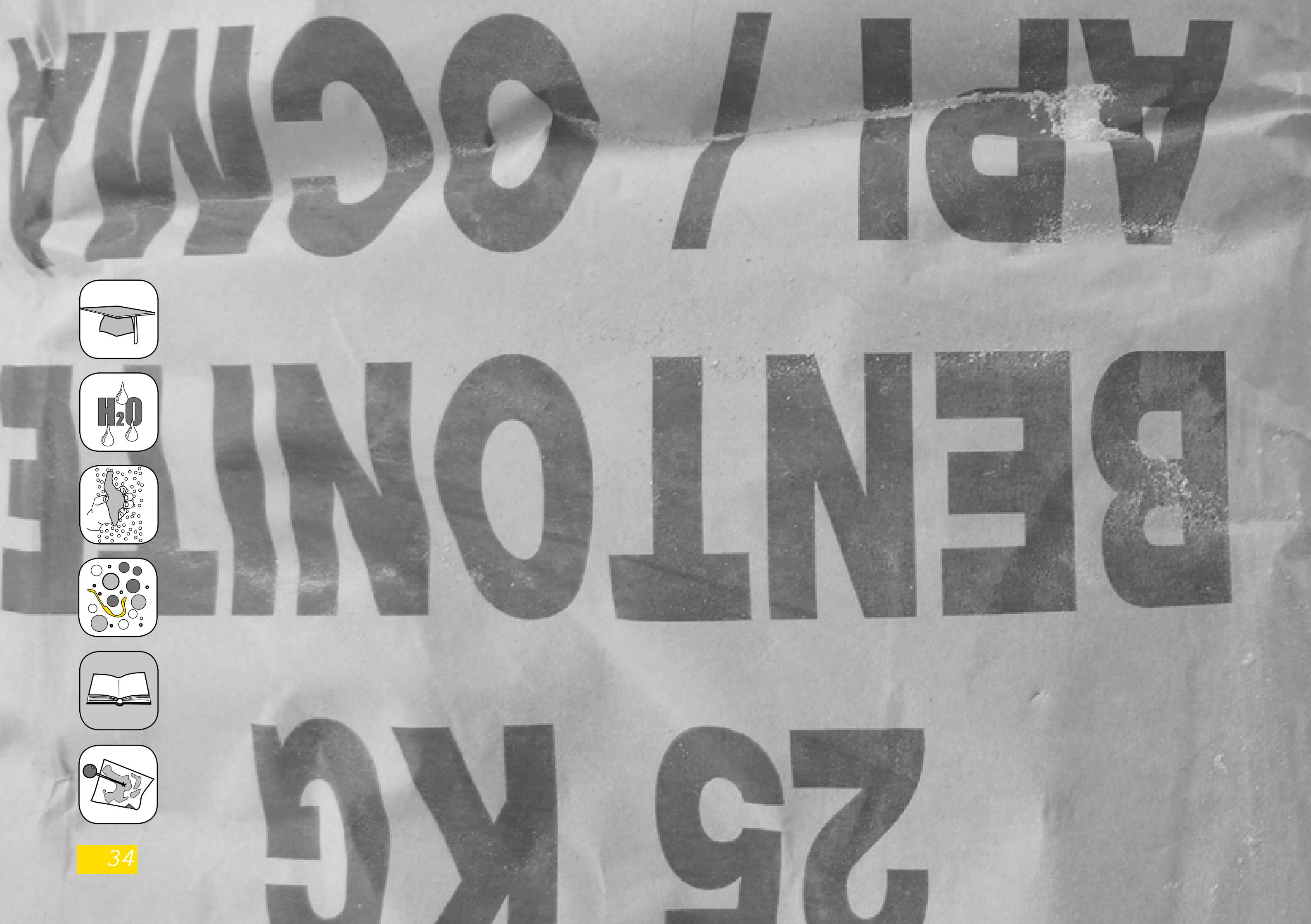
Sanitation:

According to UNICEF, only 34% of the population of Sudan have access to 'adequate' sanitation facilities[21]. As a result, disease is widespread.

19. Oxfam America, http://www.oxfamamerica.org/, 2006

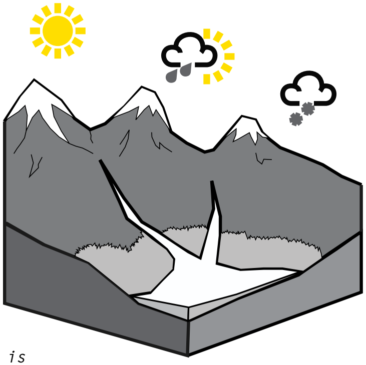
20. ibid.

21. UNICEF, 'Sudan Statistics', http://www.unicef.org/infobycountry/sudan_statistics.html, 2006

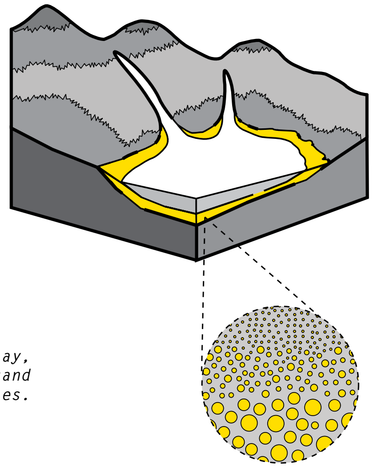

API / OCMA
BENTONITE
25 KG

from mountains to dust...soils, geology and geography

To understand the structural properties of mud bricks, we must first understand the mud itself. This section deals with the variances in soils in arid regions of the world and the different properties of the types of clay most common to these areas.



Parent material is physically & chemically weathered



This forms clay, silt & sand particles.

22. Arid, Wikipedia, http://en.wikipedia.org/wiki/Arid, accessed 29.10.2007

23. H.E.Dregne, Developments in Soil Science 6, Soils of Arid Regions, p.V, Amsterdam, Elsevier Scientific Publishing Company, 1976

24. ibid, p.167

25. ibid, pp.229,230

26. ibid, p.1

27. ibid, pp.2,3

28. ibid, p.37

29. The Sudan, Drainage and Soils, Encyclopedia Brittanica Online, http://www.britannica.com/eb/article-24333/The-Sudan, p.2, 11.10.2007

30. H.E.Dregne, op.cit p.45

31. H.E.Dregne, op.cit p69

32. Q.Wilson, Mixes For Adobes, http://www.quentinwilson.com/mixes-for-adobe/, 10.10.2007

33. G.Minke, Earth Construction Handbook, p.22, Southampton, WIT Press, 2000

An area is described as arid when it suffers from a lack of available water in the soil so severe that the development of plant and animal life is hindered.[22] Annual precipitation is generally very low, but can vary greatly from year to year, for example in Karachi for the period 1850 to 1950 the driest year received just 12mm rain, whilst the wettest received 710mm.[23]

Soil

Soil is formed by the weathering of rock, known as parent material. Climate, vegetation, topography, the type of parent material and time all affect the type of soil produced.[24] Soil comprises three main particle types, proportioned by weight: clay, $0 < 0.002$mm diameter; silt, 0.002 - 0.05mm diameter; and sand, 0.05 - 2.0mm diameter. Other components include gravel, particles 2 - 75mm diameter, and organic material.[25]

Arid-region soils

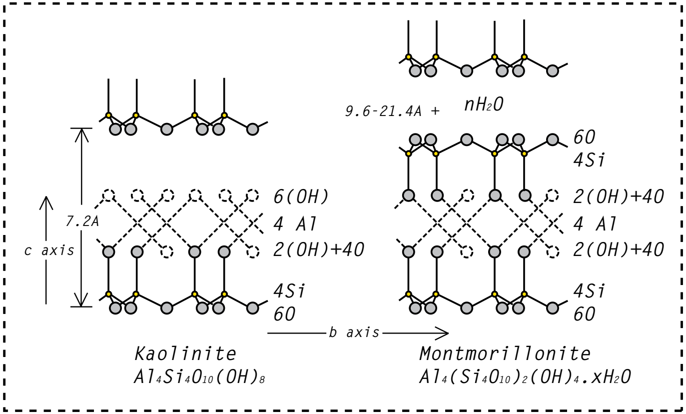
The characteristics of arid region soils differ from soils in the humid regions of the world. Typically they are of coarse to medium texture, with a slightly acid or alkaline pH in the surface layer, and contain a very low level of organic matter.[26]

Coarse, well-drained upland soils provide an excellent base for roads, except in very sandy areas. Fine alluvial soils exist in depressions and valleys and are suitable for use as a construction material where timber is scarce.[27] The most common arid soil types are classified as Entisols, followed by Aridisols, Mollisols, Alfisols and Vertisols, which each have a different characteristics.[28]

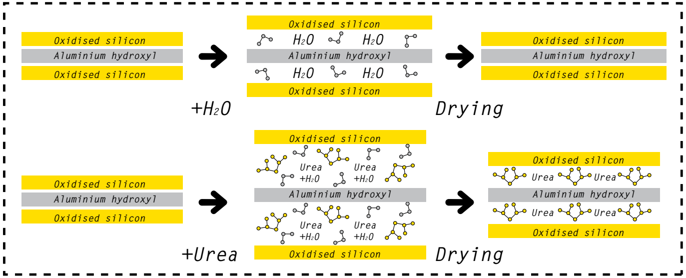
For example in Sudan, sandy soils dominate the northern and west central areas, clayey soils are present in the central plains, and laterite soils exist in the south of the country.[29] The clay plains feature a layer of very clayey soil averaging 10 metres deep above sand. Known locally as Gezira clay - a cracking clay soil of the vertisol family, a soil type with a high content of expansive clay, particularly Montmorillonite.[30,31] This causes the deep cracks formed as the soil dries and contracts in the dry season.

Use of soil in construction

For the use of soil in construction, such as cobs, adobe bricks or rammed earth, as little organic material as possible and enough clay must be present in the soil to bind it, 20 - 30% clay is ideal for adobes.[32] Organic material will break down affecting the integrity of any soil construction. Sandy soil requires the addition of clay, otherwise the soil will crumble, and clayey soil requires dilution with sand as too much clay causes shrinkage and cracking as the soil dries out. There are simple to perform field tests, which indicate the suitability of a soil for construction, and soil mixtures can be adjusted by adding sand or clay until a suitable mix is achieved.[33]



Schematic molecular structure of clay minerals



Montmorillonite and water or urea

On addition of water clay forms intercalated layer structure with water molecules. On drying this structure collapses. Similarly with urine an intercalated structure is formed, but on drying urea molecules may remain maintaining structure.

34. B.Mason, Principles of Geochemistry Third Edition, pp.157-158, John Wiley & Sons, Inc., London, 1966

35. ibid, pp.158-160

36. ibid, p.159

37. A.Sridharan & K.Prakash, "Influence of clay mineralogy and pore-medium chemistry on clay sediment formation", Canadian Geotechnical Journal, National Research Council Canada, Issue 5, Vol. 36, 1999

38. B.Mason, op.cit, pp.158-159

39. A.Sridharan & K.Prakash, op.cit

40. Professor Tony Parsons, University of Sheffeld, Interview, 3.10.2007

41. G.Minke, earth Construction Handbook, p.50, WITPress, Southampton, 2000

42. Q.Wilson, op.cit, p.185

It is clay with its fine particles which has the greatest affect on the physical properties of soil. Clay is typically formed by the very gradual chemical weathering of rocks, different rates and types of chemical weathering result in several types of clay; the main groups are Kaolin, Montmorillonite, Illite and Chlorite. Naturally occurring clays are usually a mixture of pure clays from these classification groups.[34] Clay molecules form platelets; sheet structures which in some clays can interact with water or other polarised molecules. This interaction is affected by the chemical make up of the clay, and its particle size. Expansive clays such as montmorillonite ($Al_4(Si_4O_{10})_2(OH)_4.xH_2O$), which is a 2:1 clay – a clay which contains 1 aluminium-hydroxyl unit sandwiched between 2 oxidised silicon units – can form temporary intermolecular bonds with water molecules between its platelets, a process known as adsorption.[35] This means montmorillonite clay can hold a large volume of water within its structure, physically swelling as it becomes hydrated, forming intercalated layers with water molecules sandwiched between layers of clay molecules, hence it is said to have an expanding lattice.[36] Montmorillonite has a high specific surface area, approximately 800 m^2 per gram, giving a large area for physicochemical reactions.[37]

Less reactive, non-expansive clays such as kaolin ($Al_4Si_4O_{10}(OH)_6$ which is a 1:1 clay – a clay which contains 1 aluminium-hydroxyl unit bonded to 1 oxidised silicon unit – show very little swelling on hydration, as the clay does not form a layered structure with water as montmorillonite does.[38] Kaolin has a comparatively low specific surface area of approximately 10 – 20 m^2 per gram, and is more chemically stable than montmorillonite. The responses of these two common clay minerals to physicochemical factors are quite drastic and opposite.[39]

Recreating soil

To imitate arid region soils for testing a realistic clay/sand mix must be achieved. As described above the type of clay has the greatest effect on the physical properties of the soil, whilst sand is fairly inert and typical across the globe.[40]

The two clays we will test are montmorillonite – a physically reactive expansive clay, and kaolinite – a low-activity non-expansive clay, both commonly occurring in soils, and available in the UK in dry powdered form, which we will mix with dry sand to synthesise soil. The proportion of clay in soil used for mud brick making can vary, examples range from 12% to 30%[41,42] so a suitable ratio is to be chosen for testing.


H2O