

Sustainable Use of Cement

A case study of light clay in process orientated modular construction system

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Abstract

South African government identified housing as one of the greatest challenges facing the country and adopted the Reconstruction & Development Program (RDP) in 1994.

The housing program was faced with many problems, escalating material costs, environmental impact and lack of comfort, leading to severe **housing shortages** particularly in the poorer and rural area.

Laws on national level like the BNG (Breaking New Ground) from 2004 or the Peoples Housing Process provide **strategies supporting community driven building initiatives** to overcome the backlog of adequate housing and to develop skills in areas with high unemployment rates.

To implement these new sustainable strategies an **adequate architecture and design** has to acknowledge **local resources, financial capacities and skills** and at the same time provide **quality and ecological solutions**.

Together with the local community in Ekurhuleni, a **modular construction system with light-clay infill** could be developed and established together with the FH Kärnten (Carinthia University of Applied Science, Austria) to provide an affordable and ecological building technology.

Self-produced concrete pillars support the local economy and provide the loadbearing structure, which is filled up and compacted with straw - light - clay using a climbing formwork.

The ecological and affordable modular system for low cost housing with focus on self-building provides **insulation and accumulation within the element** for comfortable room climate in winter and summer.

Advantage lies on the **availability of the prospective users** - (financially and geographically) **easy to transfer know how, appropriate technology** (as no special tools are needed) and is **workable for adaption concerning climate as well as users needs**.

Keywords

modular, low-cost housing, ecological, straw-light-clay, community involvement,

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Image 01: Ithuba Primary School, 2011

Background

Build Collective – NPO for Architecture and Development registered in 2010 with its founder members, Elias Rubin and Marlene Wagner, working in developing environments since 2006. The collaboration with universities, nongovernmental organizations, institutions, companies, artists and local communities define process and framework for each project.

The Austrian NGO s2arch, founded the Ithuba Community College in 2008. The school serves near by townships like Magagula Heights and Zonkezizwe in Ekurhuleni, Gauteng Province. The Primary and Secondary school follows the syllabus of the Department of Education but supports in addition practical skills and the arts. Since 2009 the NPO buildCollective has been involved and collaborated with s2arch, different Universities from Europe, local construction team, community and students of Ithuba.

In the past 4-years, 10 buildings of the school campus - classrooms, workshops, kitchen, staffroom extension, a hall and library, could be realized in light clay construction. The different designs of universities from Austria, Germany, Switzerland and Slovenia combine the natural insulation with steel, wood and concrete aiming comfortable room climate through north-east orientation, roof overhang in relation to winter and summer sun, ceiling and ventilation.



Image 02: Ithuba Community College, Buildings in light clay construction highlighted

The modular structure

Material

Concrete and steel provide a sustainable material not in ecological sense but in maintenance and lifespan. The wide spread knowledge of working with concrete and steel and the easy accessibility of cement and basic steel profiles provide the opportunity to involve local labor and create income generating prefabrication.

Pillars and Trusses are produced locally for each project. The design can easily adapt to local needs – orientation, size, openings and extension.

Production

A vibrating table, separated in 10 compartments each 200 x 70 mm and prepared with 6mm reinforcing rods, is filled with concrete - mix ratio 5/5/3 (45mph).



Image 03,04: Preparation and filling of vibrating table

The 3 meter long table produces 10 pillars with each load and needs one day of drying process until pillars can be taken out for further drying and preparation and the table can be prepared for casting again.



Image 05,06: Cutting of pillars and welding of truss

The foundation plate provides holes to enable easy placement of pillars in the defined loadbearing structure grid. Two constructive rings – base and top connection define fields of 1.5 to 2.5 meter length and up to 3.2 m height, to be filled up with light-clay. The steel trusses are welded from basic steel profiles like angles, reinforcing rods, square tubes and flat steel depending on need of span width. Like the pillars they can be carried and set up by hand without any machinery support.



Image 07,08: Pillars set up on concrete plate,

Costs

The material costs of one pillar (cement, stones, sand and reinforcing) derive to about 100 ZAR. For a classroom of 7 by 12 meters about 25 to 30 pillars are needed (3 loads). The additional concrete base to protect the wall infill from splash water is calculated with additional 2000 ZAR.

Roofing of the classroom demands 7 to 10 trusses, depending on the need of covered outside space calculating each for about 1100 ZAR. Here costs can be lowered through maximizing statics, design and used profiles. Together with the concrete plate the costs for the loadbearing structure (pillars and trusses) derive to about 25 000 to 30 000 ZAR or about 350 ZAR/m² excluding labor.

The ecological infill

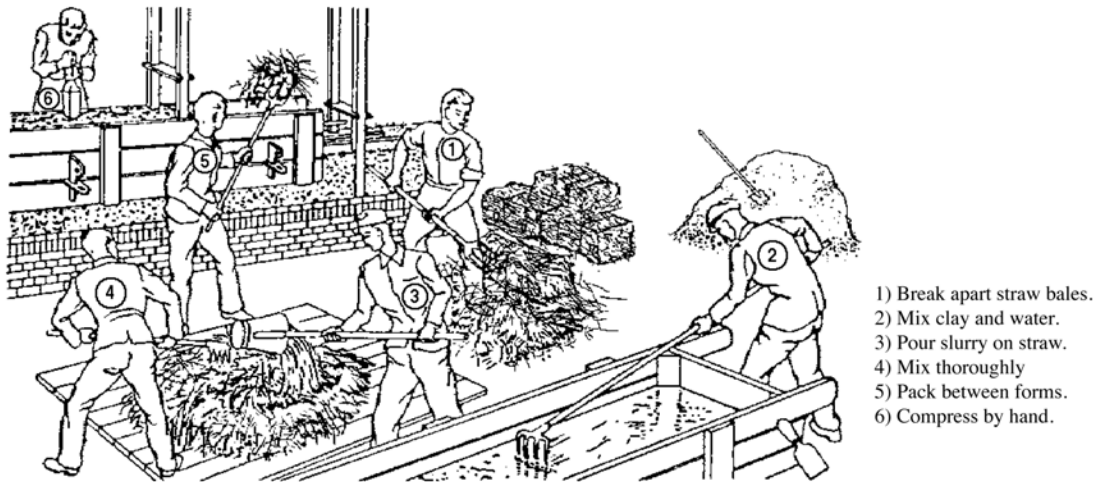


Image 09: Traditional way of straw light clay work, [1] Volhard

Background

In the whole world earth - as a local resource, serves as a traditional building material. The different ratios of clay, silt and sand, as well as climate condition (insulation vs. accumulation) define most suitable processing. Light straw -clay is an adaptation, of wattle, daub or cob. Developed in Germany it has been in use for over 600 years.

In times of energy crisis, scarcity of housing and a more conscious, environmental friendly, way of building light clay can serve as a affordable alternative providing comfortable room climate in summer and winter.

Material

The widely available and inexpensive material is renewable, non-toxic and easily processed, requiring no expensive tools, machinery or special skills. Depending on mix and quantity of additive it provides insulation, accumulation and preservation (against insects, fire) within the element and is compatible in areas with high earthquake risks.

Most suitable for straw-light-clay, balance of binding and workability- is a lean to medium fat clay of about 100 to 120 g/cm² binding strength. The clay should not content any humus or roots and can be purchased from clay brick manufactures or harvested from site. Analyzing of available soil can be easily done through ball form and ball drop tests or more specific through the binding strength test according to Niemeyer.

Binding strength g/cm ²	50 to 100	111 to 200	201 to 280	281 to 360
Description	Lean clay	Medium fat clay	Fat clay	Very fat clay

Table 01: Clay description according to [2] Volhard

The additive straw needs to be strong and without leaves, weed or seeds, most suitable in form of bales with straws of 20 to 40 cm length. The wheat, rye, or barley (more settlement) straw needs to be dry and loos to be fully covered with clay.

Production

The clay is mixed with water to a slurry consistency like a "milkshake". The more water is

added to the mixture the higher the workability and more insulation capacities are achieved but the drying period is extended. Less water provides acoustic insulation and thermal storage but also a more heavy building material.

The slump test defines consistency - 100ml, poured on a leveled surface, should show a suspension of about 13 cm in diameter.



Image 10,11: Sieving of clay and stirring device

To save time, assure binding strength and sludge the clay is sieved and mixed with a stirring device. The straw has to be fully covered with clay and needs to be covered and soak for 8 to 24 hours before further processing.



Image 12,13: Pouring slumped clay on straw and mixing

The mix ratio as well as density of the straw-light clay defines characteristics and performance of the building material. Light mixes of a density by volume of 400 to 800 kg/m³ provide more insulation and should be used for external walls. Heavy mixes of about 800 to 1200 kg/m³ provide more accumulation, acoustic insulation, useable for nails and plugs and better fire protection. [3] Volhard

Density by volume
 4 – 450 kg/m³,
 3 – 600 kg/m³,
 9 – 950 kg/m³.
 19 – 2000 kg/m³ (no straw)

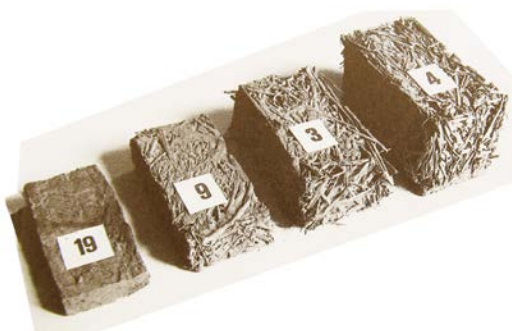


Image 14: Testing cube with same amount of clay with different amounts of straw according to [4] Volhard

Density by volume kg/m ³	Thermal transmission λ (W/mK)	Thermal resistance R (m ² K/W) Layer thickness $s = 0.10 / 0.20 / 0.30$		
400	0.12	0.83	1.67	2.5
600	0.17	0.59	1.18	1.76
800	0.25	0.40	0.8	1.2
1000	0.35	0.29	0.57	0.86
1200	0.47	0.21	0.43	0.64

Table 02: Thermal resistance according to [5] Volhard

Placing

The soaked straw is filled by hand into a climbing-form that is clamped or screwed between the loadbearing pillars. A Layer of 30 to 60 cm is scattered between the wooden boards and compacted to the desired density through stamping by feet or wood. The forms can be removed immediately and slip further up until necessary wall height is reached.



Image 15,16: Stamping of straw-light-clay and placing of windows

The size of pillars defines the wall thickness of 200 mm, which forms the outside walls of the classroom. Windows and doorframes can be set according to need during construction and are filled seamless around and on top with straw light clay.

The labor-intensive work does not need any special skills and can easily be optimized to build several walls a day.

Finish

The straw-light infill needs a drying process of several months depending on season and humidity before finish and close up with plaster. To keep respiration capacities of the infill material the top layer should minimize the use of cement but provide protection from water to the outside.



Image 17,18,19: Walls in drying process, Layers of Plaster, inside classroom

In collaboration with the Japanese clay-plaster expert different plaster mixtures could be developed on site. The first layer is applied directly on the wall without additional lathwork and reinforced with natural jute fiber before the floated top layer. Clay plasters, with small straw fibers, clay sand lime plaster for inside and lime cement or lime sand cement plaster are usable for outside. Especially for fire protection requirements the plaster is important to protect the infill material, which can reach a classification of F 30 to F 90 of DIN (30 to 90 minutes fire resisting). [6] Volhard

Costs

One cubic meter of straw is about 150 ZAR and serves depending on compacted density of the wall for about 5 m² of 200 mm walls. The costs for clay vary much depending on source but can be estimated with 500 ZAR. One cubic meter of clay lasts for about 8m² of wall depending on mix ratio and quality. Straw light clay wall filling can therefore be calculated with approx. 120 ZAR/m², which is slightly more expensive to concrete blocks but serves a much better room climate.

Future Perspective

Build collective aims to create a non-standardized, certified building material and ready-for-use product for educational facilities and housing. In collaboration with European and South African universities like the Witwatersrand Faculty of Engineering and the Built Environment, further research and data can be collected to optimize the affordable ecological construction method. In a sustainable process with local communities, academy and other players an alternative path of hands on approach and social responsibility can lead to new possibilities reducing the lack of adequate housing and communal facilities in poor areas in the country.



Image 20,21: Workshop and staffroom extension

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