BUILDING WITH EARTH – 30 YEARS OF RESEARCH AND DEVELOPMENT AT THE UNIVERSITY OF KASSEL

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Summary

In 1975 the “Forschungslabor für Experimentelles Bauen“ (FEB) (Building Research Institute) was founded by the author at the University of Kassel, Germany. Since thenn 30 research and development projects were conducted in the field of building with earth.Thousands of tests were made in order to analyze the different characteristics of various loams (clayey soils) in respect of mechanical resistance and thermal and hydraulic behaviour and in order to optimize them by changing the grain size distribution, by improving the preparation process and by adding organic and mineral additives. New test procedures were developed in order to measure the stability against rain, abrasion and mechanical impacts.

Furthermore traditional techniques for rammed earth and adobe vaults were optimized and adjusted to modern conditions and new techniques developed: like the extrusion of loam profiles for wall construction, pumping of lightweight loam for walls and floors and a calculation and construction technique for large domes of adobes or earth blocks, which can be erected without formwork. By this technique, which guarantees that no ring forces and no bending forces will occur in a dome, more than 20 domes were built with un-stabilised earth blocks all over the world. The largest dome has a free span of 11 m, a height of 7 m and a structural thickness of only 30 cm.

Within three research and development projects five different prototypes of earthquake resistant houses were built of earth in earthquake prone zones in South America and a full scale adobe vault was successfully tested on the earthquake simulation shaking table of PUCP, Lima, Peru. The paper portrays the 30 years of R&D experience of building with earth at the University of Kassel and dissemination of the knowledge across several countries.

Keywords: Material tests, techniques, domes, earthquake resistant structures

1 Introducing remark

The building material earth is used with different expressions in combination with building elements: Handmade unburnt bricks are normally called adobes in America and mud bricks in Asia. If they are industrially produced in an extrusion process they are called green bricks, if they are produced in a press they are named compressed earth blocks. The words “clay brick” and “clay wall” or “clay plaster” are incorrect as clay is only one part of the building material earth. In this paper the scientific word “loam” is used when earth is used as building material, which consists of clay as a binder and silt, sand and sometimes also gravel and larger stones as aggregates.

2 Material tests

In the eighties and nineties of last century several thousand tests of different samples of loam, of clayey soils from all over the world were tested in order to get a range of characteristics for linear shrinkage during the drying process, compressive, tensile and bending strength, absorption and desorption (release) of humidity, water and vapour diffusion and equilibrium moisture content.

In order to optimise these characteristics special treatments and aggregates were tested. One result of silty loam mortars for instant was that additions of 2 % to 6 % cement will normally not increase but decrease the resistance against compressive forces (**Fig. 1**).

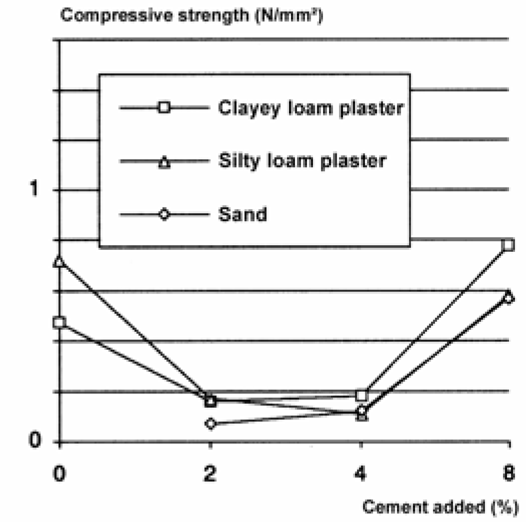

Fig. 1 Change in compressive strength of loam (mud) mortars and sand with the addition of cement

The tested silty loam showed a decrease of compressive strength from 2.2 N/mm² to 0.4 N/mm² when 2 % cement was added. Even with 4 % cement addition the strength was still reduced by two thirds. It has to be mentioned here that this effect differs due to the kind and amount of the clay minerals.

A similar but not so much reduction in compressive strength is noted with the addition of lime (**Fig. 2**). **Fig. 3** shows the effect on the tensile bending strength of earth plasters due to cement addition.

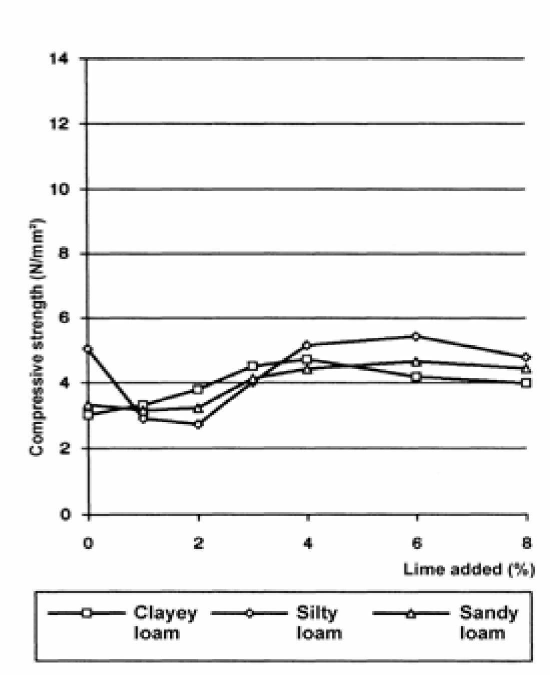

Fig. 2 Change in compressive strength of loam with addition of lime

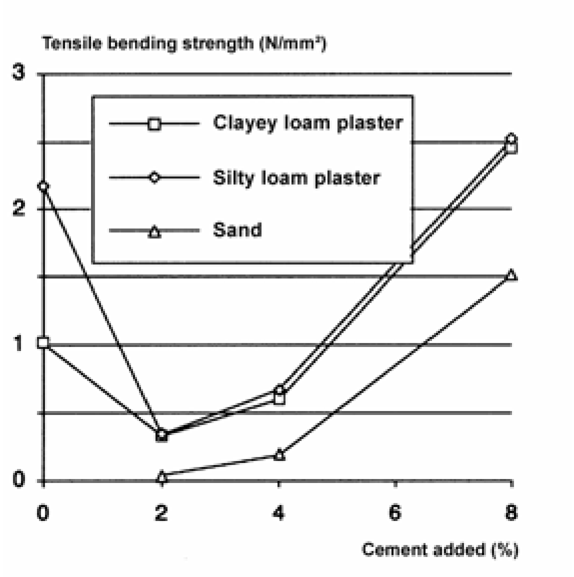

Fig. 3 Change in tensile bending force of loam with addition of cement

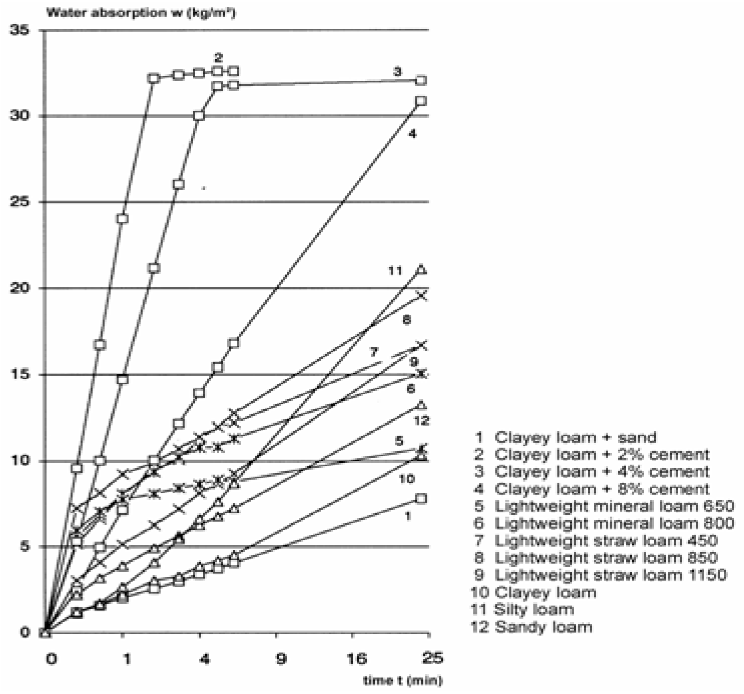

Fig. 4 Water absorption of loams

It was also found that the water absorption (not humidity absorption) increases extremely if only some cement is added. **Fig. 4** shows that the surfaces of a sandy clayey loam absorbs about 2 litres of water per sq. m. after 1 hour, whereas the same loam with 2 % of cement absorbs 24 litres and with 4 % of cement still 3.5 times as much as without cement. It can also be seen that silty loams absorb more water than clayey loams. That means adding cement stabilises loam surfaces only against running water (rain) and against abrasion. But if mud mortar with little cement is applied over a mud brick wall, the high water absorption which means high capillary water transport, creates problems on the mud brick surfaces, which then tend to swallow.

If the grain distribution and clay content of a loam is acceptable, there is no need to add cement, which increases cost and environmental pollution.

Another result showed that earth walls absorb indoor humidity more than any other solid walls. When the indoor relative humidity of the air is higher than 50 % they absorb humidity and when it is lower than 50 % they desorb (release) humidity, thus balancing indoor humidity (**Fig. 5**). In this test 15 mm thick samples, sealed on five sides, where put into a climatic chamber. After a sudden raise of air humidity from 50 % to 80 % the unburned earth block showed 10 times more absorption than the burned brick and 50 times more than a clinker brick after a period of 2 days.

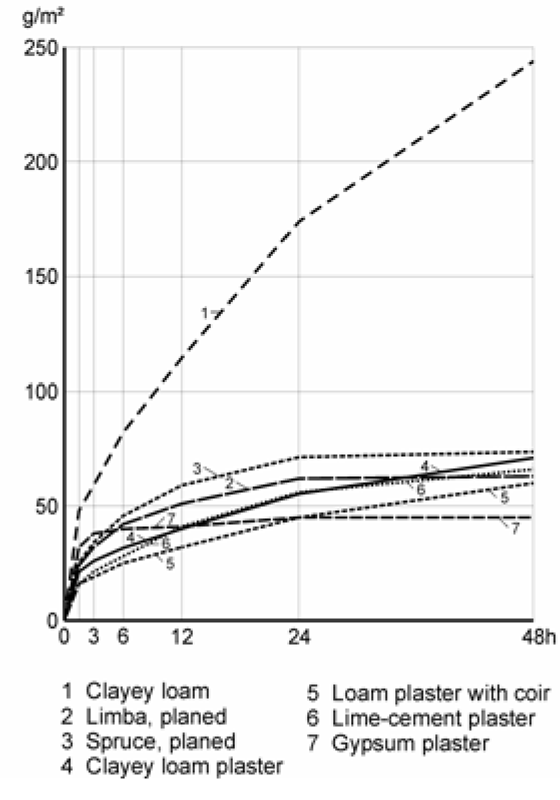

Fig. 5 Absorption of samples, 15 mm thick, at a temperature of 21 °C and a sudden increase of humidity from 50 % to 80 %

Measurements over period of several years in the author's home, where all walls and the domed roofs are of loam, revealed that the relative humidity was about 50 % throughout the year, with peaks which only varied by 10 %.

An interesting effect of the building material earth, which was discovered, is its high absorption capacity of high-frequency electromagnetic radiation, as created by mobile phones and digital electric cordless phones (**Fig. 6**). Shelter against this kind of radiation is getting of increasing importance in high density population areas, like Germany, where more and more people get health problems caused by this radiation.

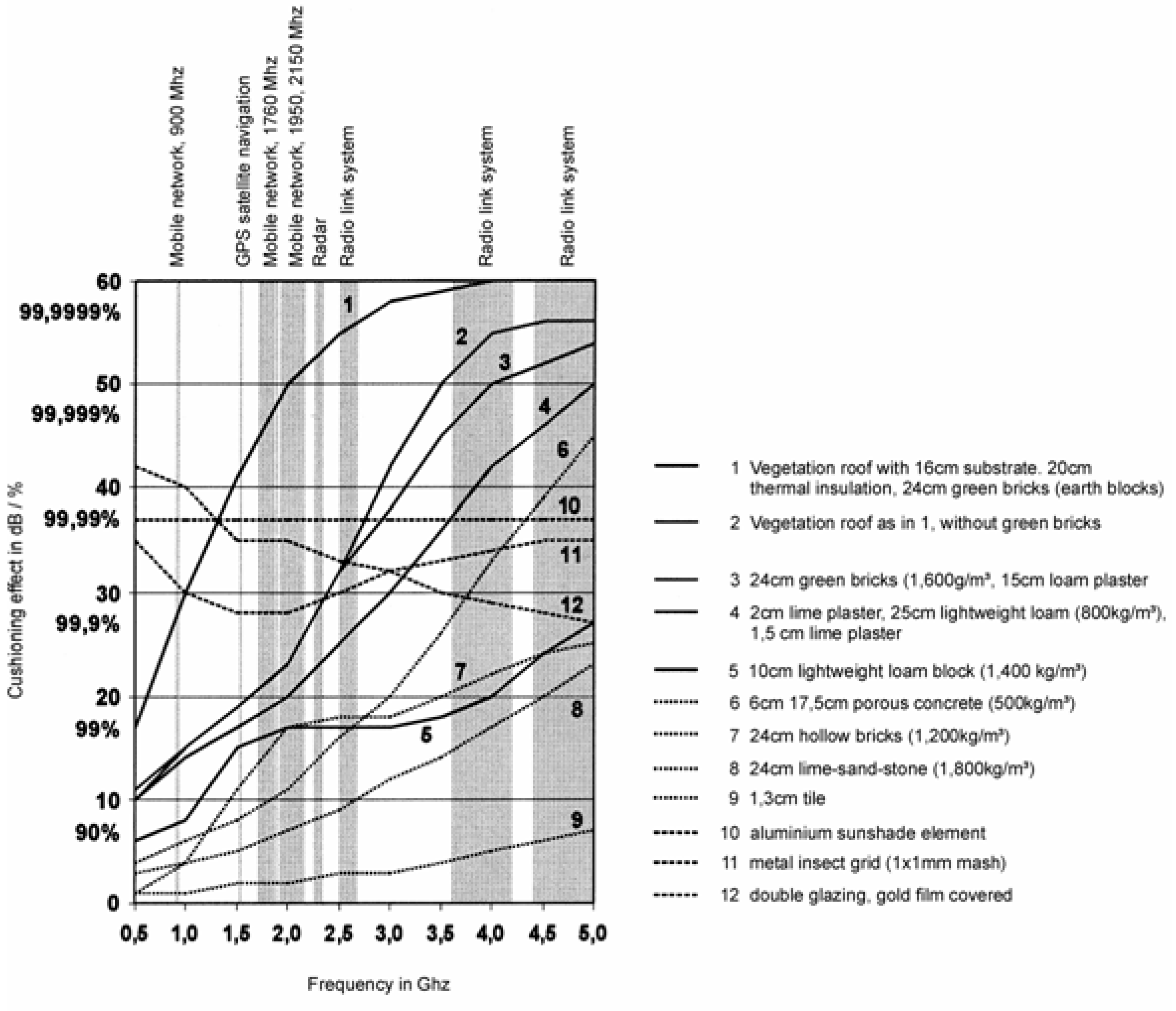

Fig. 6 Shelter effect of different building components against high-frequency electromagnetic radiation

In an area of 2 gigahertz an adobe wall of 240 mm thickness showed a shelter effect of 22 decibel (dB), equivalent to 99.4 %, whereas a wall of burnt bricks showed 17 dB and a wall of lime-sand-stone only 7 dB. The highest effect of reduction was measured under a vault of 240 mm of unburnt (green) bricks and a vegetation roof with 160 mm of substrate. In an area of 2 gigahertz this shelter gives a reduction of 99.999%.

Besides these common tests three new test procedures for earth components were developed in order to determine the resistance of loam surfaces against rain impact. A test apparatus was developed in which water jets of 4 mm diameter sprayed onto 6 samples simultaneously with a velocity of 3.24 m/sec, simulating the heaviest driving rain conditions in Europe (**Fig. 7**). Results show that after 4 minutes erosion starts on the surface of a common silty loam, whereas the same loam mixed with 30 % of cow-dung, showed erosion only after 60 minutes. The same earth mixed with 6 % of cooked linseed oil withstood the water jet seven days without showing any erosion. Based on these results of these tests the author used in his private house by building sinks of stabilised loam. **Fig. 8** shows a sculptured sink in his guest toilet, stabilised by linseed oil and **Fig. 9** a sink in the bath room, made from raw earth, stabilised by 6 % of glue prepared from casein (the protein of cheese) and lime. Other organic and mineral stabilisers were tested and used for outside mud plaster of straw bale walls (Minke and Mahlke 2005).

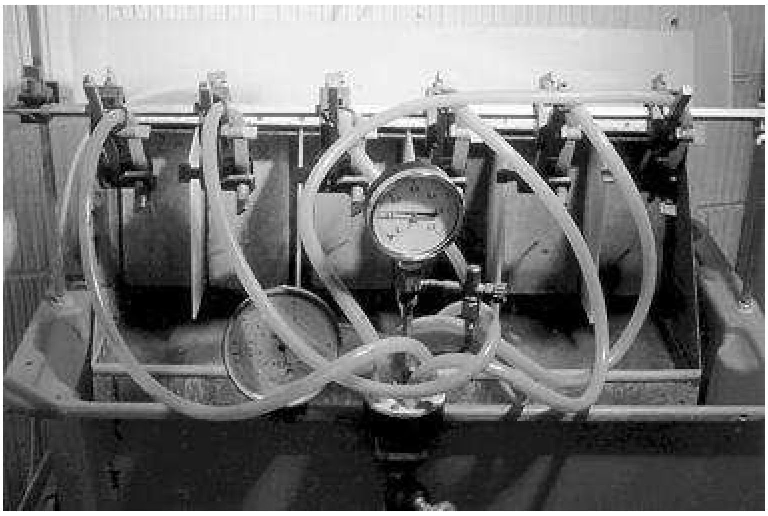

Fig. 7 Test apparatus to measure rain erosion

Fig. 8 Wash basins from stabilised loam, residence at Kassel, Germany

Fig. 9 Wash basins from stabilised loam, residence at Kassel, Germany

As loam surfaces like mud plaster and earth floors are sensitive to abrasion, a test apparatus was developed which measures the resistance to abrasion: A strong plastic brush is rotated on the surface under a weight of 2 kg (**Fig. 10**). After 20 cycles the amount of abrasion is recorded through the weight. **Fig. 11** shows the test results of 15 different mud plasters available on the German market. The results vary by a factor of 30.

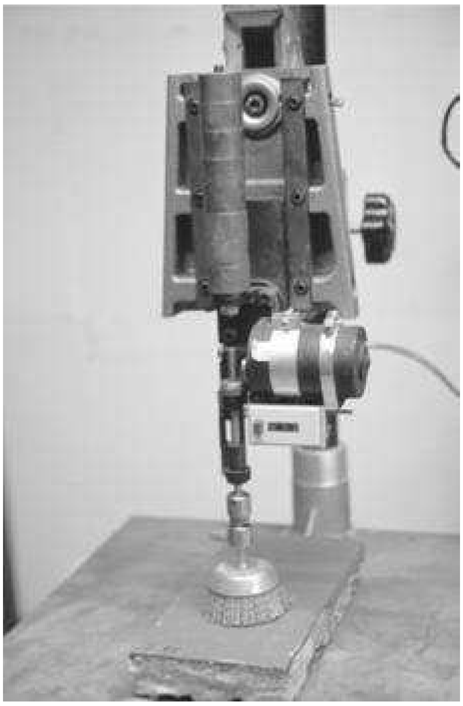

Fig. 10 Apparatus to test the resistance against abrasion

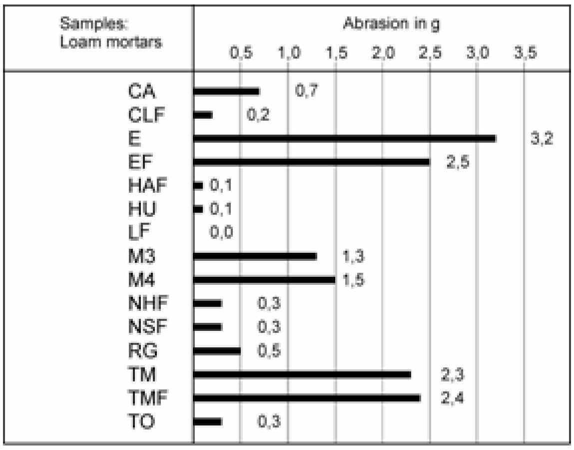

Fig. 11 Amount of abrasion of different loam plasters

As corners of mud bricks and earthen construction elements are sensitive to mechanical impacts a special apparatus was developed to measure the strength of corners against dynamic impacts (**Fig. 12**). A weight in the shape of a semi-spherical steel ball 30 mm in diameter is dropped onto the surface at an angle of 60 degree, with 10 mm distance from the corner.

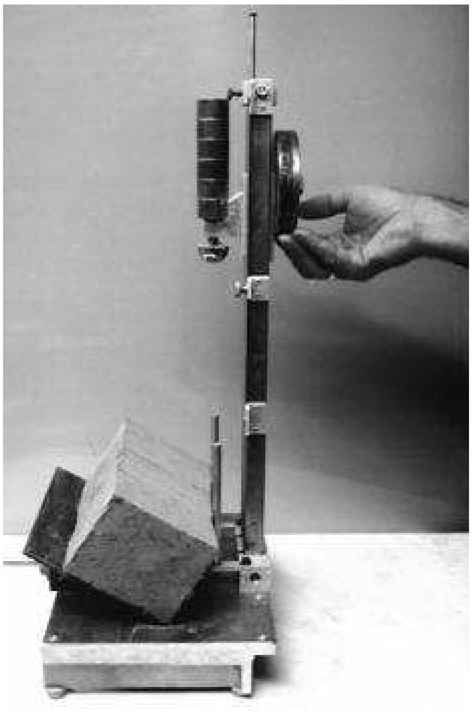

Fig. 12 Apparatus to measure the strength of corners against dynamic impacts

3 Refined and new developed techniques

In 1982 a new construction technique was developed using extruded loam profiles, stacked one layer upon the other in a plastic state without using mortar (**Fig. 13**). The joints were finished by pressing them with bare hands or with a stick (**Fig. 14**).

Fig. 13 Extrusion of loam profiles and stacking in a plastic state

Fig. 14 Extrusion of loam profiles and stacking in a plastic state

As lightweight-walls built of loam and straw often show fungus and have a high shrinkage, experiments were made with different light weight mineral loam, earth mixed with pumice, expanded clay, expanded slag and others. It was found that loam mixed with light mineral aggregates in an optimum proportion showed a linear shrinkage of 0 % during the drying process. This mixture was pumped into walls. In 1992 the author used this technique of pumping the mixture it into cotton hoses, thus having a flexible element of packed earth to build walls and furniture (**Fig. 15, 16**).

Fig. 15 Interior walls of lightweight loam-filled cotton hoses

Fig. 16 Interior walls of lightweight loam-filled cotton hoses

In order to build domes of large spans without formwork a new technique was developed in 1987. It is based on the assumption that in a structurally optimised mud brick dome all bending and tensile forces are avoided for large spans and thin walls. The structural optimal geometry was developed by a computer programme. In order to achieve this geometry when building the dome and in order to avoid an expensive formwork a rotational guide was developed (**Fig. 17**).

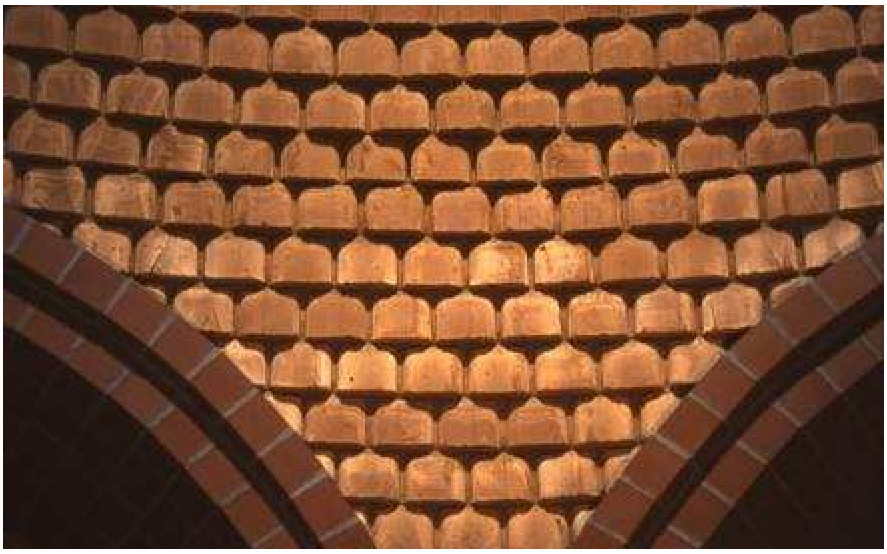

Fig. 17 Advanced rotational guide to build domes

In order to optimise the acoustic behaviour of large halls a special acoustic adobe was developed. This adobe has rounded corners to give better sound distribution and by the depressed joints some sound absorption occurs. The multipurpose halls utilizing these adobes proved to have a perfect acoustic behaviour for concerts. **Fig. 18** shows the multipurpose hall of a Kindergarten designed by the author. The largest dome of unstabilised unburned earth blocks so far built, has a free span of 11 m and a height of 7 m. It was designed by the author for a multipurpose hall for a Kindergarten in Germany.

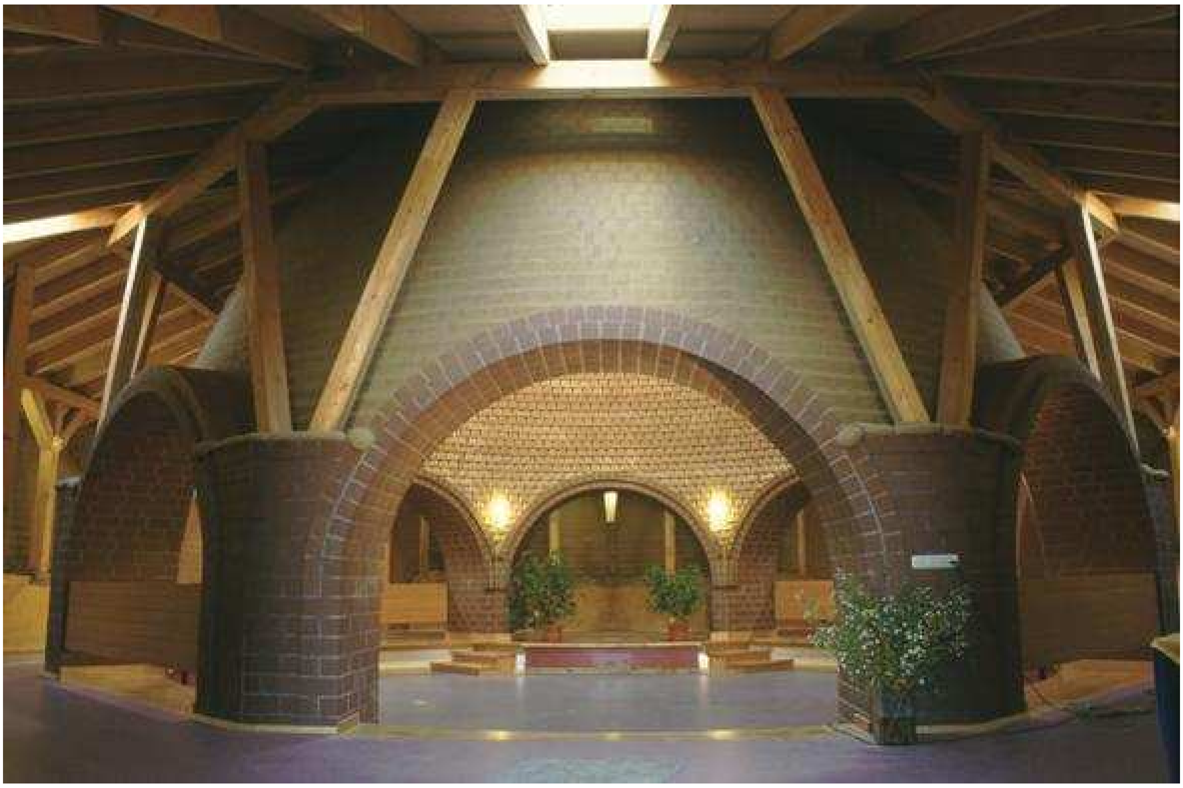

Fig. 18 Multipurpose hall, Kindergarten at Sorsum, Germany

The research work done in the field of earthquake resistant houses built of earth are documented in [1].

More data and details of the research and development work on building with earth are available in “Building with Earth – Design and Technology of a Sustainable Architecture” [2].

References

[1] MINKE, G. *Construction Manual of Earthquake Resistant Houses built of Earth Eschborn*. 2002 (This report of 50 pages can be downloaded from http:// www.asl.uni-kassel.de/~feb/wissenswertes/manual_engl.pdf)
[2] MINKE, G. *Building with Earth – Design and Technology of a Sustainable Architecture*. Birkhäuser Publisher, Basel/Berlin, 2006
[3] MINKE, G.; MAHLKE, F. *Building with Straw*. Birkhäuser Publisher Basel/Berlin, 2005

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