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Traditional and Modern Techniques for Building Vaults and Domes from Earth

GERNOT MINKE

Techniques for building vaults and domes from adobes have been known for thousands of years. In the last few years some of these techniques have been improved and adopted for modern building by reducing material and labor costs and optimizing their structural behavior.

This essay presents the Nubian vault technique, which was optimized and applied to modern projects in India, South America, and Germany. It further presents dome building techniques, historically used in Persia and Afghanistan, that have since been applied to modern housing in Germany, and a new technique for building domes with a span of up to thirteen meters diameter and a wall thickness of only thirty centimeters without formwork utilizing a special rotational guide. More than forty domes of this type have been built so far in Germany, Slovakia, Greece, India, Egypt, Uruguay, Paraguay, Argentina, and Brazil.



Fig. 01. Nubian vault, more than 3,200 years old. Photo by Gernot Minke.

Nubian vaults

Nubian vaults from handmade adobes in Sudan, Upper Egypt, and Iran have been known about for many thousands of years. Figure 01 shows a vault from the temple of Ramses II, which is more than 3,200 years old. These vaults can be built without any formwork by using reclining arches, if the inclination is between 65 and 70 degrees [Fig. 02]. For structural reasons, in order to give optimal stability, the cross section of the vault should be an inverted catenary. While historic structures in Egypt have rectangular adobes measuring 15 centimeters in width, 25 centimeters in length and 5 to 6 centimeters in thickness, at the *Forschungslabor für Experimentelles Bauen* (FEB) (Building Research Institute), University of Kassel, the shape of the adobes were changed: Instead of rectangular adobe square ones, measuring 20 × 20 × 6 centimeters, were used at the bottom part of the arches and tapered ones at the upper part. So, the joints were smaller, which leads to higher stability and savings in mortar and time.

For earthquake-prone areas the author developed a pre-stressing system for Nubian vaults. They are pre-tensioned by steel strips, which are tightened to the reinforced concrete beam, which acts as foundation [Fig. 03]. Equal pre-tension forces are ensured by using a calibrated torque wrench. This system was successfully tested on the earthquake shaking table of the Catholic University at Lima.[1]

Afghan domes

In Afghanistan, a technique for building domes without formwork has been used for centuries. The process is demonstrated in figures 04 and 05. The traditional domes normally cover rooms of up to 4 × 4 meters. Figures 06, 07, 08, and 09

1. A video of this test can be seen at http://gernotminke.gernotminke.de/videos/



Fig. 02. Construction of a Nubian vault.
Photo by Gernot Minke.



Fig. 03. Full scale test on shaking table, Catholic University
Lima, Peru. Photo by Gernot Minke.

show the adaptation of this technique by the author in his residence.

Persian domes

In Persia a similar technique for covering square rooms with domes without using formworks has been known for thousands of years. Here reclining arches begin from all four corners of the base. Figure 10 shows a model of just such a dome with wind catchers.

As it needs a lot of skill and calculation, so that the four arches join in an exact zig-zag line, the author used an easy method to get the right pattern by forming the shape of the dome beforehand with humid sand [Fig. 11, 12].

Nubian domes

The Nubian dome technique has been known in Upper Egypt for thousands of years. In this technique circumferential courses of adobes are laid using a movable guide or a string to create a spherical shape [Fig. 13]. As tensile ring forces occur in the lower part, which destabilize the structure, only small domes with relatively thick walls can be built with it.

Spherical domes

With the Nubian dome technique, which has been known in Upper Egypt for thousands of years, circumferential courses of adobes are laid using a movable guide or a string fixed to the center to create a spherical shape. With adobes of less than forty centimeters, the diameter should be less than four meters.

Figure 14 show the construction of a Temazcal, an indigenous sweat lodge from the Americas. It was constructed during a four-day workshop led by the author in Brasil in 2016. The foundation and the plinth were made of local stones fixed with cement mortar. In order to save mortar and achieve a more rigid structure, conical adobes were used for the dome. Their position was controlled by a string fixed at the center of the base on an embedded steel bar. For an easy and quick control, the string ends at a steel angle, which is held by a counterweight [Fig. 15]. The surface of the dome is plastered by an earth mortar. The final cover can come from a lime plaster, acrylic paints, bituminous roof paper, shingles, or a plastic membrane with a green roof [Fig. 16].

Pointed adobe domes built with eccentric guide

For domes with a span of four to six meters it is favorable to use an eccentric rotating guide. Even if in this case compressive ring forces might occur at the bottom, this is less of a structural problem. But these forces can be avoided if the resultant force is within the center third of the adobes. Figure 17 illustrates the usage of this kind of eccentric rotational guide at an adobe dome with a four-meter diameter built in Slovakia. The position of the joint, where the guide moves over a horizontal axis, must be found by trial and error, checking different positions till a point can be reached where the curve still runs within the inner third of the adobe.

Structurally optimized domes

In order to be able to build large domes with thin walls, a new type of rotational guide for a structurally optimized dome shape was developed by the author at the FEB. The basic idea was to choose a geometry, which guarantees that no tensile ring forces and no buckling occurs in the dome. That means that all forces, which occur under the dead load of the dome, are transferred in the middle of its wall thickness in a vertical plane. The section of this optimized dome shape, which was derived by a computer program, is quite different from a

catenary, which would be the optimal section of a vault but not of a dome [Fig. 18]. The developed rotational guide guarantees this curve. Figure 19 shows the first simple version of this guide and figure 20 an improved one, where the leading curve is no more at the outside and no longer interferes with scaffoldings.

Figure 21 depicts the inside view of a multipurpose hall of a kindergarten in Germany, which has an interior span of ten meters and was built of unburned clay bricks. As seen in figure 22, in order to reduce the sound focusing effect of this dome, three measurements were taken: the rounded corners of the unfired bricks distribute reflected sound waves, their inclined position reflect waves upwards, and the wholes which appear at the bottom of the bricks as well as the cut-off joints give a sound absorptive effect. The largest dome so far built of handmade adobes, has a free span of 11 meters and a height of 7 meters. It was built in 2022 in Paraguay [Fig. 23].

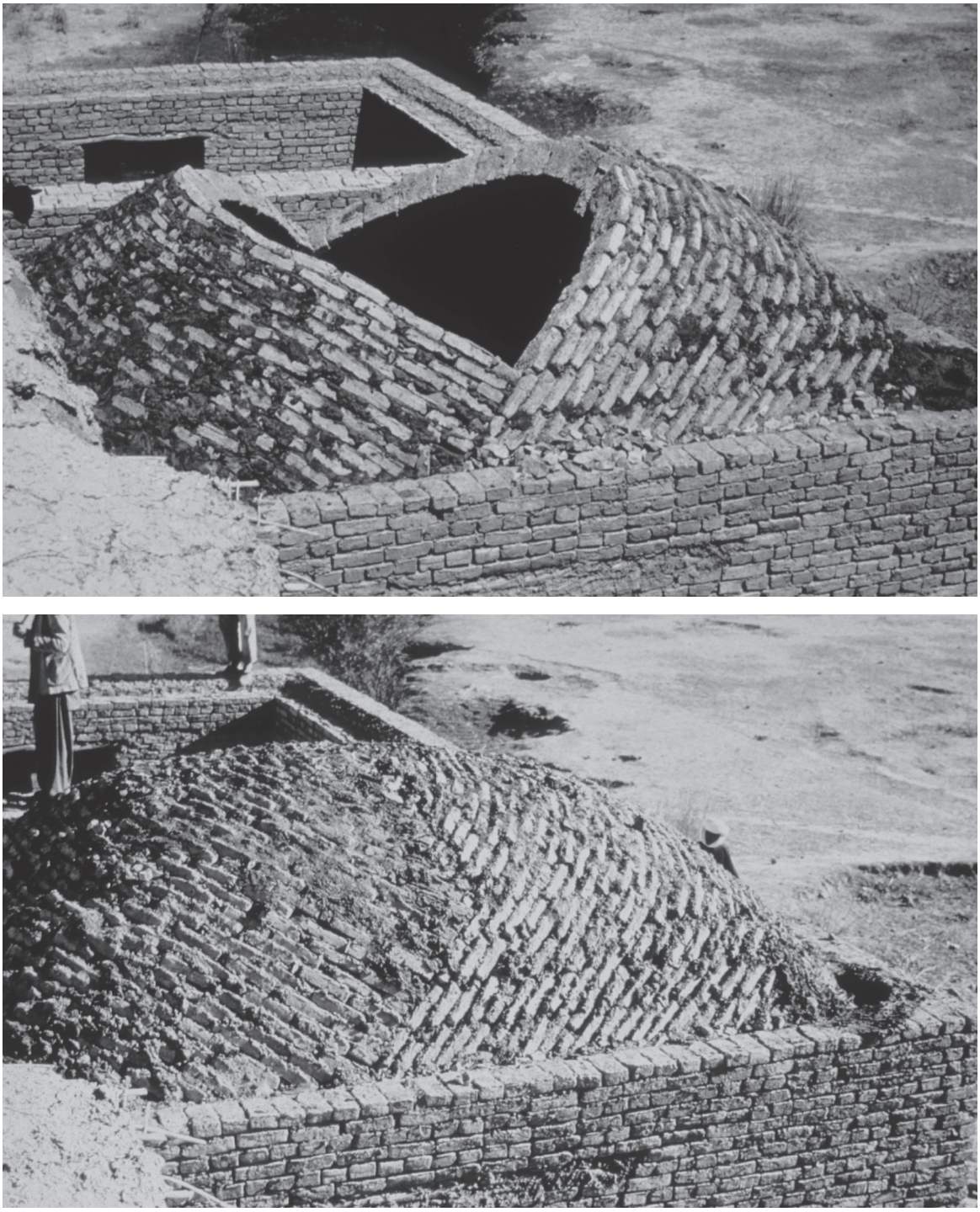


Fig. 04, 05. Traditional Afghani dome technique. Source: H. Yazdani. 1985.
Erhöhung der Lebensdauer von Lehmbauten in Erdbeben-gefährdeten Gebieten Afghanistans.
Dissertation, University of Kassel: Faculty of Architecture.



Fig. 06-09. Modern domes based on Afghani dome technique. Photos by Gernot Minke.









Fig. 10. Model of Persian dome with windcatcher.
Photo by Gernot Minke.





Fig. 11, 12. Dome built on a formwork of humid sand. Photos by Gernot Minke.

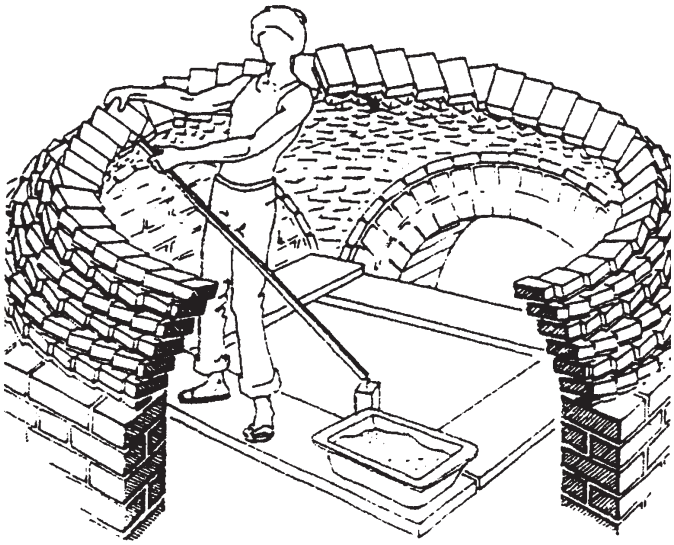


Fig. 13. Traditional Nubian Dome technique. Source: CraTerre. 1979. *Construire en terre*. Paris: Editions Alternative et Paralleles, 235.



Fig. 14. Temazcal, TIBA, Brasil. Photo by Gernot Minke.

Fig. 15. Counterweight.
Photo by Gernot Minke.



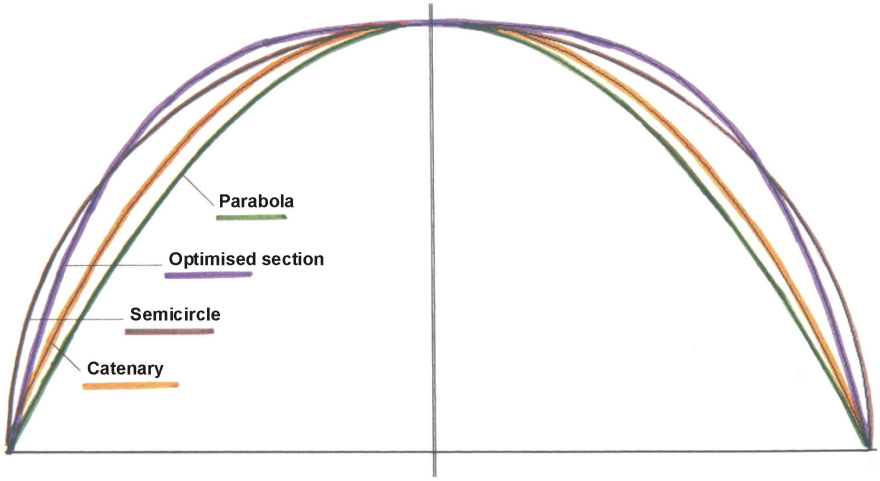


Fig. 16. Adobe dome covered by green roof. Photo by Gernot Minke.



Fig. 17. Eccentric rotational guide.
Photo by Gernot Minke.

Fig. 18. Optimized section in relation to well-known curves. Diagram by Gernot Minke.



Ideal curve for a dome in comparison with a parabola, catenary and semicircle.



Fig. 19. Simple version of rotational guide, IIT New Delhi. Photo by Gernot Minke.



Fig. 20. Improved rotational guide, Rocha, Uruguay. Photo by Gernot Minke.



Fig. 21. Multipurpose hall, kindergarten at Sorsum, Germany. Photo by Gernot Minke.





Fig. 22. Detail of “acoustic” adobes.
Photo by Gernot Minke.

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- CRAterre. 1979. *Construire en terre*. Paris: Editions Alternative et Paralleles.



Fig. 23. Multipurpose hall, Emboscada, Paraguay (under construction). Photo by Gernot Minke.

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