The Use of Earth in the Architecture of Hassan Fathy and Fabrizio Carola: Typological and Building Innovations, Building Technology and Static Behaviour

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INTRODUCTION

Unfired earth is the most common building material in the world: nearby 1/3 and maybe even half of the world's population lives in buildings made of unfired earth. The remaining 2/3 of the population – maybe 50% – live in the other constructive typologies: in steel and in reinforced concrete houses, but also in ancient and modern buildings made either of wood or brick.

This kind of building is widespread in many countries in the world **(fig. 1)**: lots of towns in South. America are built with adobe, part of the great wall of China and some Buddhist temples are made of unfired earth. We can find throughout Europe rural buildings built using different techniques. In the Middle East all the traditional architecture is made of adobe or pisè or cob (Houben and Guillaud 1989). Moreover in the developing countries unfired earth is really the most widespread material.

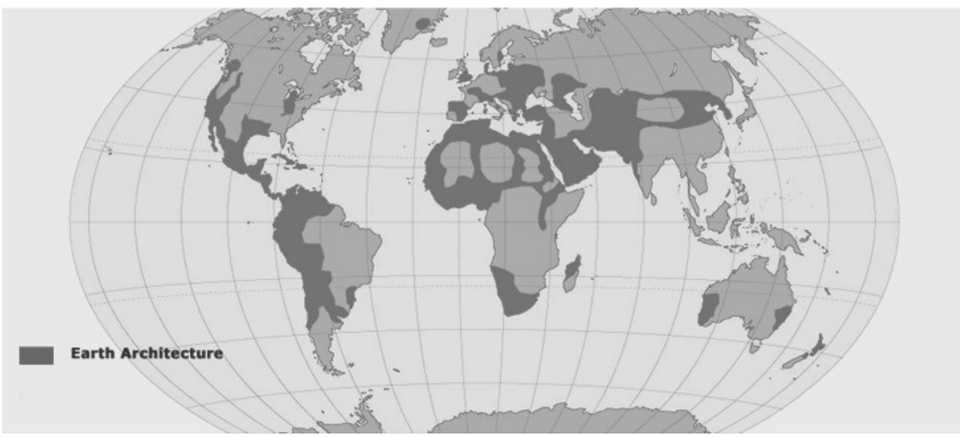

Figure 1. Distribution of unfired earth architecture in the world (http://www.terracruda.com/architetturadiffusione.htm)

For many years earth architecture has held a minor role. It was often linked to poor housing and self-building phenomena and as such it wasn't considered worth being studied in depth.

The search for materials at a low environmental impact due to the energetic crisis of the 1970s caused the re-approach of the world of architecture to unfired earth. Since then several research study centres have been created regarding this material. First of all, the UNESCO has included in the world's patrimony 96 sites totally or partially built in earth. **(fig. 2)**.

Figure 2. View of Shibam (E. Francaviglia de Gregori 2003)

The Getty Conservation Institute of Los Angeles working together with UNESCO has developed some methods of intervention on existing buildings in unfired earth, while the International Centre of Buildings in Earth, CRATerre EAG of Grenoble, deals with both ancient and modern building techniques, paying particular attention to the identification of the physical, chemical and mechanical properties of the handmade. These are the leaders of a network of studies which is widespread at various levels: from universities to professionals who chose to use, in their architecture, unfired earth.

Also in Italy, although later, a culture of architecture based on principles of ecological sustainability has developed. Among the building materials used, unfired earth has found fertile ground in Sardinia, where the use of this material belongs to the local building tradition. Here the IMTerra Association was born, inside which several professionals work, such as the architect Alceo Vado, appointed manager of the association, designer and advisor for the realisation of the Elderly Center in Sestu. This work represents a moment of practical application of the construction theories that have been studied and developed inside the association: it is built in structural masonry made of unfired "lateres" intertwingled with vertical strings made of fired bricks of the double UNI kind, placed at constant intervals. The structure ends with strings in reinforced concrete wrapped in lost moulds in fired bricks.

Fabrizio Carola is Italian too. The Neapolitan architect was born in an area without a building tradition in unfired earth but when he happened to work in Africa, he felt the need to use a material which was congenial to the socio-cultural, economical and constructive needs of those places. So he chose earth as building material and the work of Hassan Fathy as his inspiration source.

HASSAN FATHY

Hassan Fathy was born in Alexandria, Egypt in 1900. In 1926 he graduated in architecture at Cairo University. His first project was the Talkha Primary School in neoclassical style, then he worked during his career in Egypt and Greece.

There are many of his written works dealing with architecture, such as *Gourna: A Tale of Two Villages* [1969], *Architecture for the Poor* [1973], *Natural Energy and Vernacular Architecture* [1986]. He also collected during his latest years several acknowledgements: the Aga Kahn Award for Architecture, the medal of the union of international Architects, the honorary Doctorate awarded by AUC.

His gouaches alone could perfectly describe his work **(fig. 3)**, but we'd like nonetheless to hint at the general principles as guidelines to understand them. Fathy believed in the importance of human values, in the use of technology suitable to time and place [that is climate and local economies], in the need for socially-oriented cooperative construction techniques. He assigned an essential role to tradition and hence to the re-establishment of a national cultural pride, a goal to attain by means of the act of building (http://www.kmtspace.com/kmt/fathy.htm).

The Egyptian architect was intellectually stimulated by the art of the pharaonic period and was directly influenced by vernacular architecture. He studied the buildings of the old city of Cairo and Nubia in order to create a national architectural language based on the employment of traditional elements and building techniques. His projects are based on the use of a narrow vocabulary made of morphological and structural elements taken from tradition: parabolic arches, square spaces covered with domes, rectangular rooms or narrow spaces with vaults, courts, balconies wind towers (Fantone 2003). Both for the value he attributed to manual work and for economical and ideological reasons, he resorts, for the realization of his projects, to traditional techniques that extremely reduce the use of machinery and exploit what is available in a cheap way: earth, straw, man's labour, stones. The brick is in fact the only material used in his works. The supporting walls are made either of sun dried bricks made of mud and reinforced with straw (adobe) or of local stones or fired bricks [often for the foundations]. Before starting to build with earth Fathy asked structural engineers and soil mechanic specialists for advice to be sure of the maximum strength and durability of adobe under different loading conditions. It was only after the experimental results that he began widely employing the material (http://www.saudiaramcoworld.com/issue/199904/elegant.solution.htm). The question of the roofs remained, for which we quote his opinion, he writes:

> If the farmer manages to build the walls easily he cannot build the roof as well. The roof requires materials capable of bearing bending moments and tensile stresses such as wood, reinforced concrete etc. These materials aren't locally available and must be bought. Since ancient times people from Egypt, Iran and Iraq conceived a clever system to build roofs with mud bricks thus solving the problem of tensile stress and strength of the material by using the geometry of shape. They built the vault shaped roofs with the profile of a catenary curve thus eliminating tensile stresses and bending moments, and making the vault surface endure the sole compression. They conceived a simple and naïve method to build these vaults, which were erected in space without the need for centrings and supports They reached this result by building the vault in subsequent rings with the bricks gradually placed on a slightly inclined plane with respect to the vertical axe, leaning on a found wall.
>
> (Steele 1997)

Figure 3. Gouache (Picone, A, 2003)

In 1941, he discovered that the masons of the Nubian village Abu al Riche built vaults with mud bricks without centring using a very ancient technique which had been used for thousands of years to build houses, graves and royal palaces. He started to use this technique in his project for the Rural Hospital. Not only in elevation structures then, but also in covering ones he will make use of earth thanks to the great employment of the Nubian building technique which will be dealt with in the following paragraphs. By studying Egyptian wall paintings he found the tool that was used by ancient builders to makes domes. In contemporary Nubia he sought local workers who kept the memory of this tool: When making domes, they used a string anchored to a rivet fixed into the ground in the centre of the circular space to be covered. They used to place at the free end of the string a wooden bar orthogonal to the string itself, that worked as a guide to the proper positioning of the bricks. Fathy re-makes this “compass” in wood **(fig. 4)**.

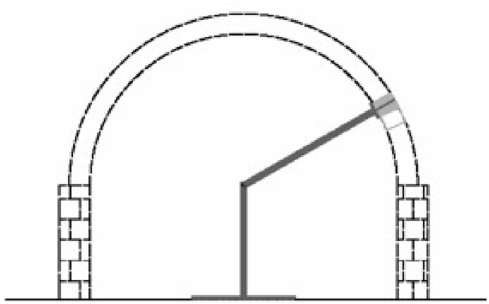

Figure 4. Fathi compass

FABRIZIO CARòLA

Born in Naples, he graduated from the National High School of Architecture of Bruxelles [La Cambre] in 1956. He opened in Bruxelles his first office, then graduated at Naples University in 1961 in Architecture.

In 1972 he went to Mali in Africa and began to study the local techniques and put them into practice by building a restaurant in unfired earth bricks measuring 20 x 40 cm. For the roof he employed arches and vaults instead of prefabricated common joists and sheet metals **(fig. 5)**. These arches were built upon centrings made of the same bricks of the construction, drawing from a kind of roof existing in the Dogon tradition, the people from the near Bandiagarà tableland.

Unlike Fathy who was African-born and therefore brought into his work technical, formal and typological elements belonging to his own culture and tradition, Carola, even though working with the full respect for the place and for the users of his architecture, makes his project choices by responding to the issues aroused each time by the project: he asserted that the logic followed in designing is based on the fulfilment of the problems’ data. In his African architectural projects reinforced concrete, iron and wood have been eliminated: the first two ones because imported, the third one because the cutting of the few trees existing in those places would have helped to increase desertification. He makes only use of the local resources: stone and unfired or fired lime. During the1980s he designed for l'Association pour le dèveloppement naturel d'une Architecture et d'un Urbaniste Africain [A.D.A.U.A no longer existing now] the Kaedi Hospital [Aga Khan Award for Architecture in 1995]. The work was realized by using the local lime which was fired in a furnace built near the site [fuelled with rice chaff], to obtain fired bricks: 40 workers made 2.5 million bricks for this project. Local workers were properly trained to accomplish the conceived work by exploiting, revisiting, reinterpreting in modern idiom their ancient building tradition (Sicignano, 2000).

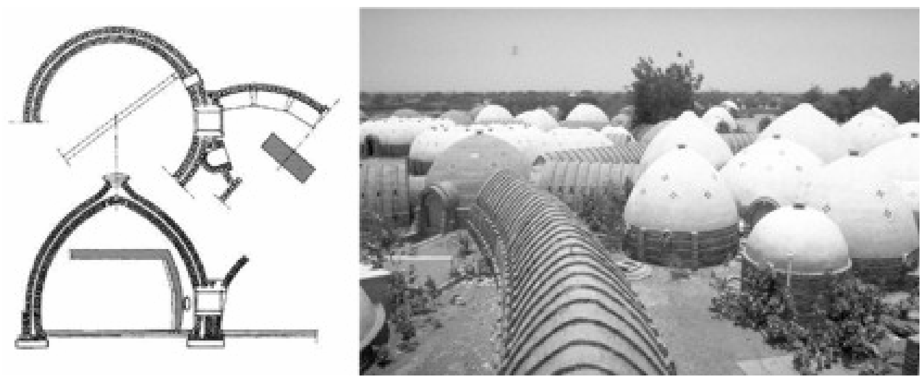

Figure 5. Kaedi Hospital

Later Caròla bettered the compass technique in order to obtain ogival domes with a longer internal diameter and so a greater circulation of air. He therefore modified the system by fixing the compass to a cart thus moving the pin from the centre of the dome: in this way he obtained a longer arm moving up and down and drawing the pointed generatrix as will be dealt with in the next paragraph.

VAULTS AND DOMES WITHOUT CENTRINGS

The mechanical properties of adobe, its lack of tensile and shear strength have always been a problem for ancient builders when they had to design roofs. In archaic architectures they first used cane and rope mats on a wooden structure. This means an increase of the construction costs especially in an area where the wood is scarce. Then they decided to use for the roofs the same material used for the walls, thus creating vaults and domes where the material is mainly compressed. This well-known problem has been properly solved by traditional building techniques both in building phase and in the shape of the finished structures, especially in Egypt and in the region of Ancient Nubia: the Nubian vaults were already used in the XIII century B.C., as witnessed by the Vault of the granary in the mausoleum of Ramses II in Thebe [XIX dynasty] **(fig. 6)**.

Figure 6. Ruins of the granary of the Ramesseum in Thebe (www.egyptologica.be)

Nubian vaults are built without centrings and this is possible thanks to the stickiness of the mud mortar, the shape of the vault and the inclination of the courses that are placed one upon the other and finally on the supporting wall which was thicker than the lateral walls. The basic vault form, thanks to the builder's experience, was very similar to that of an inverted catenary.

In the 1970s, the International Association Development Workshop [DW] developed the "Woodless Construction" program, in the Sub-Saharan Sahel. Conceptually this method of construction does not use wood for the support of the structural parts of the building–walls/roofs-, and uses instead hand-moulded earth bricks. This experience is particularly interesting as there has been a continuous evolution of technology which considered and responded to functional and technical needs including the limited economic resources (Norton 1997). For the construction of roofs, generally reference is made to the Egyptian and the Nubian tradition but introducing changes in the building technologies and instruments. As for the construction of vaults the section of the vault was partially modified to make the construction work easier for the local workers, who did not have the technical know how to build. The technique used in the construction of such vaults **(fig. 7)** consisted in the building of a high wall at the bottom of the space to be covered on which the curvature of the vault was drawn and then the following method is used to draw this profile:

1. dividing the span in three equal parts and fix in the two intermediate points two wire length of 1/3 of the diameter;
2. connecting two wires to the other extremity and to this attach another wire of the same length;
3. tracing the shape of the vault is sufficient to maintain the free extremity of this last wire and let it rotate from one end to the other of the spring;

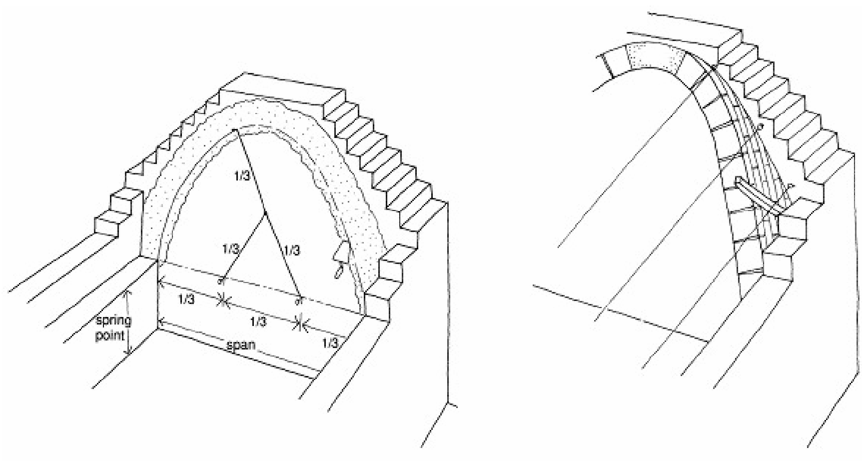

Figure 7. Phases construction of vault

Following the draw the builder digs a mark onto the terminal walls on both sides of the space to be covered and begins to lay the bricks. Then he starts to construct a series of arches made of square bricks placed face to face, whose plane was not perfectly vertical but slightly inclined - that is on the thick wall on which the corresponding form has been traced - and proceeds on both sides helped by the guidance wire insuring the horizontal alignment of the bricks. Using of the adhesive quality of the bricks basic composition, and contemporarily, of the inclination of the various portions of the arch one proceeds up to the centre of the space to be covered. Here the two halves of the vault meet and the problem of how to have them meet precisely arises, thus often horizontal rows of bricks are used to close the space **(fig. 8)**. The thrusts of the inclined arches combines with the thrust of the vertical arches thus obtaining a barrel vault behaviour once the mortar is dried.

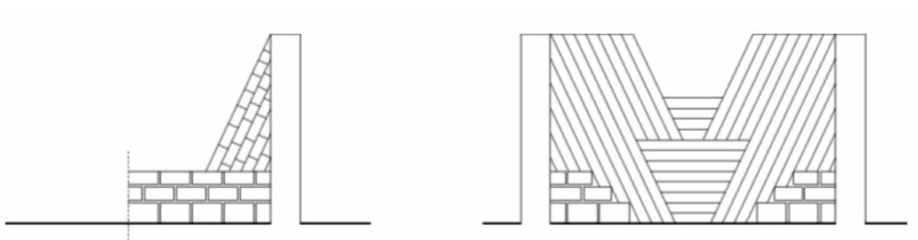

Figure 8. Closure of the space with horizontal brick courses

We have verified **(fig. 9)**, as confirmed by John Norton, that the profile of the transversal section of the vault described above is very close to an inverse catenary considering the thickness of an arch of 15 centimetres. and a depth of 100 centimetres, this ensures principally a compressive stress on the bricks of the vault.

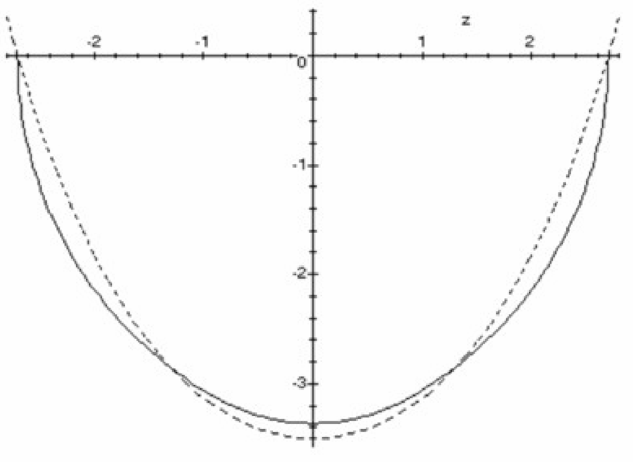

Figure 9. Polycentric curve (continuous) and catenary function (hidden)

Another very ingenious way of building the roofs using the adobe is that of domes. The basic dome shape used in Egyptian tradition is hemispherical. Horizontal concentric courses of bricks are laid first at a shallow angle and then more sharply inclined as one builds the concentric rings higher and towards the top. The distance from the centre of the dome and the angle of each brick is given by a wire or a radial arm which rotates around a central post. The adobes are placed side by side until a complete concentric circle of bricks is closed to form a compressive ring. A single dome can cover rectangular or round spaces **(fig. 10)**. In the case of rectangular spaces it is possible to use two techniques: building pedentives or building squinch arches.(Norton 1997)

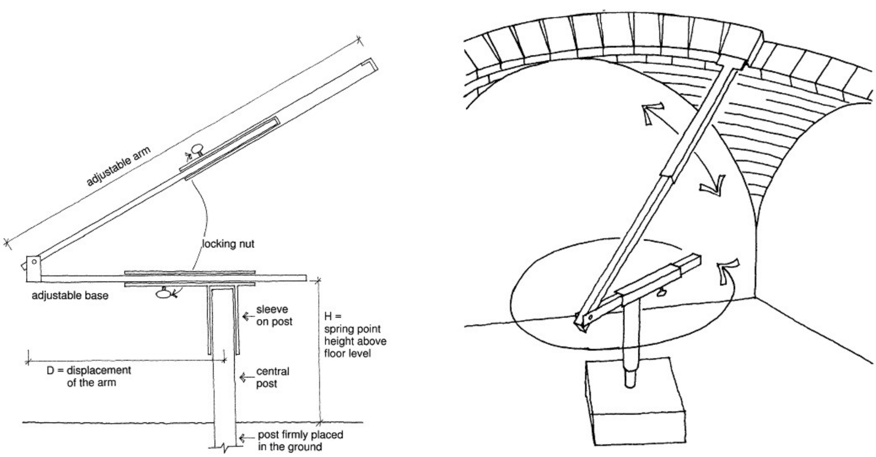

Figure 10. Building of the dome

In the construction of the domes prismatic ashlars are used and the setting of them generates cuneiform joints. They have the function of bearing the tensile force along the parallels. The hemispherical dome produces external thrusts in the lower part of the structure which does not suit the use of unstabilized earth bricks. One can help this by making the angle of the dome sides steeper. Caròla obtained these results displacing the guiding arm from the centre of the dome.

With the aim to find the load collapse multiplier in case of seismic load we used a simple numerical method by linear formulation founded on the static theorem of the limit analysis. We modelled a dome in adobe adopting a discretization by blocks containing a certain number of bricks considering the following mechanical features:

- modelling in rigid blocks;
- inability to carry tension for the contact interfaces;
- limited compressive strength at interfaces;
- provision for blocks to slide with dilatancy.

The software we used has been developed by Anselmi et all (Anselmi, De Rosa, Fino, 2004) by means of Excel program solver. This software has been created for the analysis of traditional masonry in Campania tufa. The greater ductility of adobe's masonry compared to the Campania tufa keep the results in security.

We have carried out same application for an axi-symmetric dome with the following geometric features:

- length of covered span $L = 2\ R_0 = 6$ metres
- ogival profile with eccentricity $e = 1/3\ R_0$
- width $2\ s = 0.5$ cetre

Because of symmetry, we analyse one dome slice, discretized by six rigid blocks **(fig. 11)**. The utilized yield domain of the material is that, defined in (Anselmi, De Rosa, Fino 2004), for sliding and rocking with a limited compressive strength $\square_{lim}$ = 4 Newton on square millimetre and an angle of friction $\square_0 = 1$ [which means infinity friction].

We obtained a computational result concerning this dome for a horizontal load at the springs □□□□□ This load multiplier compared with that of an adobe dome with hemispherical shape [□□□□□□showed that the ogival profile is not stabler.

If we increase the strength of material considering the features of tufa or well done adobe like $\square_{lim}$ = 7 Newton on square millimetre the previous static multiplier increases for the ogival dome like

̣̣□□̣and for hemispherical dome like ̣̣̃ı̣̃We would underline this model does not consider the high ductility of earth masonry that we would take into account in a future research.

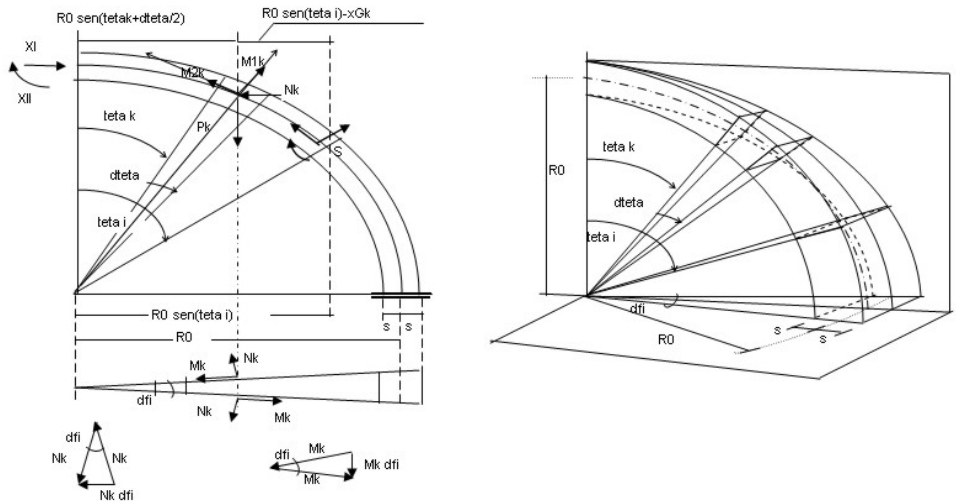

Figure 11. Axi-symmetric dome application (Anselmi, De Rosa, Fino, 2004)

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