The Nubian Vault: Earth roofs in the Sahel

T. Granier[1], A. Kaye[1], J. Ravier[1] and D. Sillou[1]

[1] Association la Voûte Nubienne (AVN), 9 rue des Arts, 34190 Ganges, France
Tel : +33 (0)4 67 81 21 05; Email : *contact@lavoutenubienne.org*

Abstract

This paper describes a modern adaptation, simplification, and codification of the ancient Nubian vault roof-building technique, developed and implemented on a significant scale by the *Association la Voute Nubienne* (AVN) in Burkina Faso during the last six years. The AVN programme *Earth roofs in the Sahel* has undertaken the construction of over 200 vaults to date (mainly houses, but also including a church, a mosque, and several small hotels). This VN technique enables the construction of environmentally sound, well insulated, adobe / earth buildings with roofs which require neither timber nor metal sheeting – hence a valid and significant alternative to traditional flat-roof buildings of the Sahel, and to the more recent use of imported corrugated iron sheeting. The specific adaptations of the original technique include the use of a simple device to define the curvature of the vault, the strict specification of the depth of foundations and the thickness of gable and lateral walls, the use of embedded plastic sheeting in the roof to enhance impermeability to rain, and the speed at which apprentices can learn the technique on-the-job. Examples are given of the ways in which standard, modular, house designs can be adapted to specific clients' needs, and of how the use of earth bricks can be combined with more modern materials such as concrete beams, and cement, where appropriate.

Full details of the AVN's work, with many photos, and a video of construction methods and completed buildings, can be found at www.lavoutenubienne.org .

Keywords: Nubian vault, Earth construction, Timberless construction, Sahel, Sustainable building, Community involvement, Modular building, Apprenticeship

1. INTRODUCTION

The technique of building unsupported vaulted roofs from sun-dried earth bricks (adobe) dates back at least 3,500 years, to the Nubian region of the Upper Nile – hence the term 'Nubian vault'. The contour of the vault approaches that of an inverted chain, or catenary curve, the ideal shape for a vault under compression [1]. The oldest Nubian vault structure still standing, built of earth bricks, dates back to 1300 BC: the granary vaults of the Ramasseum, Old Gourna, Egypt [2]. For centuries, this age-old method of building has persisted in many semi-desert and arid regions of the world, where timber is scarce: one example is Afghanistan [3]. However, the technique largely remained unchanged, and confined to such regions, until the 1940's, when it was notably revived

by the Egyptian architect Hassan Fathy, with the building of a new village at Gourna, near Luxor [4]. Architecturally, this village is a singular success; however, the families who were moved there soon abandoned it to return to their original homes. Furthermore, the buildings at Gourna, with their domes and large vaults and other complex adaptations, required levels of skill which demanded significant training for local builders to achieve the necessary competences.

A further example of a modern re-invention of the technique can be seen at Auroville, in India (Pondicherry), using dried adobe bricks to build a structure which is then fired *in situ*, after construction [5] – a complex technique requiring large amounts of timber for the firing, but resulting in strong weatherproof buildings.

A major drawback to the adoption of the Nubian vault technique outside regions where it is indigenous has been the time needed for builders to gain the necessary skills – traditional Nubian builders would spend years as apprentices before being able to work on their own, and the two modern adaptations cited above are not easily transposable without major training inputs.

Recently, however (since 1999), some builders in Burkina Faso, working with the the Franco-Burkinabe organisation, *l'Association la Voute Nubienne* (AVN), have managed to implement a simplified and codified version of the age-old technique in the Sahel. Apart from an earlier, smaller scale, initiative (in Niger, by the *Development Workshop*), this is the first time that the technique has started to be used on a significant scale in West Africa. During the last six years, the AVN and its associated builders in Burkina Faso have constructed over 200 vaults (mainly village homes, but also a Catholic church and a mosque). These environmentally sound, comfortable, and aesthetic buildings require neither imported sheet metal for the roofing, nor expensive and increasingly rare timber beams. Over 40 Burkinabe builders, as well as some from Mali and Togo, have been trained in the technique, and there are as many apprentices currently undergoing on-the-job training on building sites. The programme organised by the Association (*Earth roofs in the Sahel*) is developing rapidly year on year in response to demand from rural families, with many requests for help and technical advice coming from the countries of the Sahel.

This article reviews the AVN's programme, and the ways in which it can respond to the challenges of building in rural areas of the Sahel (desertification, lack of timber, high cost of imported building materials...) by developing vernacular skills and using readily available local materials (i.e. earth) for sustainable and ecologically sound housing. The unique factors that differentiate the Association's programme from other initiatives which on the surface, could appear similar, are described. They are to do with the simplicity of the VN (*Voute Nubienne*) technique, its standardisation, its modularity, and the fact that training of builders is carried out in the community, on-the-job, on actual VN sites (and not in formal training centres which, by definition, are removed from the local community).

2. THE VN CONCEPT

2.1 The challenge of building in the Sahel

In sub-Saharan Africa, timber has always been used, traditionally, for roofing (flat beams and rafters made from rough timber and branches, supporting laths covered in earth; such roofs are supported by adobe / mud walls, incorporating load-bearing timber posts). Population growth in recent times, together with increasing

desertification and regression of forested areas, means that these traditional building techniques are no longer feasible. People in rural areas now have to resort to buying sheet metal (corrugated iron) and sawn timber beams and rafters for roof-building.

Figure 1: Traditional and 'modern' roofing in the Sahel

These imported building materials, with their deplorable thermal, acoustic, and aesthetic properties, are often beyond the means of many people. They have to be paid for in cash, often a problem for families living outside any formal economic system. Finding the necessary funds becomes a major drain on family resources, and does nothing to promote sustainable development.

In an experimental attempt to find a way of responding to these challenges, in the Spring of 1998, a Burkinabe builder (Seri Youlou), and a French builder (Thomas Granier), at the invitation of PIAMET, erected two prototype vaulted buildings in Boromo (central western Burkina Faso), entirely from earth bricks and earth mortar, without using any timber either for shuttering or in the structure of the buildings. The following year, with some technical advice from *Acroterre* (at the School of Architecture, Grenoble), and the help of local people wanting to get involved, two larger buildings were constructed, showing that the technique could in fact be popularised and adopted. Because of this promising start, in 2000, the AVN was formally established as a logistical support base for the Programme of *Earth roofs in the Sahel*, a programme that has since shown exponential growth from year to year.

2.2 Simplification and codification

The principal reason why the AVN's programme has developed over the last six years is due to the way in which the vault-building technique has been simplified and codified so as to enable rural builders and farmers, already familiar with earth brick fabrication and construction, to assimilate the technique within a relatively short period (i.e. during the traditional winter / spring building season, when agricultural work is minimal). The only raw material used is earth, for making both mortar, and mud bricks dried in the sun, timber shuttering is not needed to support the vault during construction, and existing traditional methods have been simplified and adapted to provide protection during the short but heavy rainy seasons of sub-Saharan Africa.

In more detail, a number of specific innovations distinguish the VN technique:

- A strict specification of building requirements for foundations, side walls, gable walls, openings, and, of course, the actual vaults, which, empirically, should not exceed an internal width of +- 3.2 metres (see *Annex: VN Building Guidelines*, for details).

- The use of a stranded guide wire stretched between the two gable walls, along which runs a ring with a standard length of cord, to define a constant radius for the initial definition of the vault.
- The transformation of the upper section of the vault from a semi-circular to an ogival shape, empirically, by the addition of a finger's length to the radius for each succeeding course of bricks over 70 degrees (thus approaching the ideal, Nubian, catenary curve).
- Use of specially made bricks for the vault, composed of high quality earth (e.g as made for granaries) mixed with straw, with optimal dimensions of +- 24 cm long X 12 cm wide X 4.5 cm thick, light enough to stick to the fresh mortar near the top of the vault.
- The inclination of the brick rows of the vault to a lower angle than vertical (+/-60°), to make the already built rows bear a part of the load of the rows actually being built.
- Use of oil drums as temporary supports for forming window and door arches.
- The use of plastic sheeting over the roof, covered by a final waterproof rendering (at least 6 cm deep) to protect it from solar degradation, and to reduce the annual maintenance load for the roof.

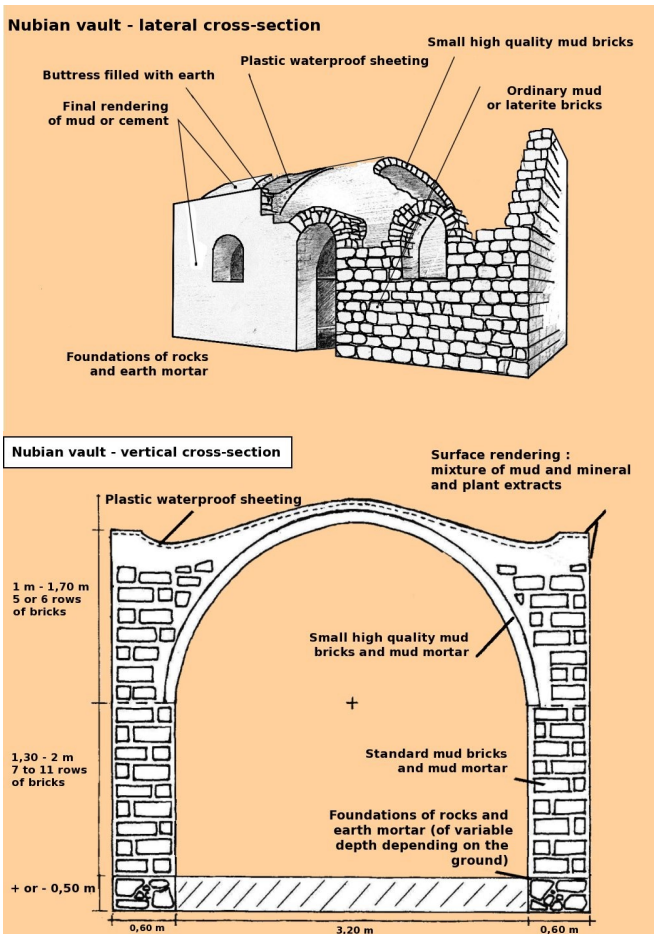

Figure 2: Lateral and vertical cross-sections of a Nubian Vault house

2.3 Modularity and customisation

The AVN has prepared for builders and clients five standard house plans, based on different permutations and combinations of one or more basic vaulted units; these range from a two-bedroom house to a simple 'bachelor pad'.

The plan for a house of 52 sq metres of living space (2 bedrooms, living room, shower, and kitchen) is shown in Figure 3. The labour required for such a house is around 26 man-days of two builders, and the same again for two apprentices and two labourers; materials needed are 30 barrows of laterite rocks, 4300 large bricks (c. 38cm X 18 cm X 18 cm), 130 barrows of ordinary earth for the walls, 70 barrows of good quality earth for the vault bricks and mortar, and 150 barrels of water. An example of a completed house of this type is shown in Figure 4. Examples of the other basic plans and associated labour and materials can be found on the AVN website [6].

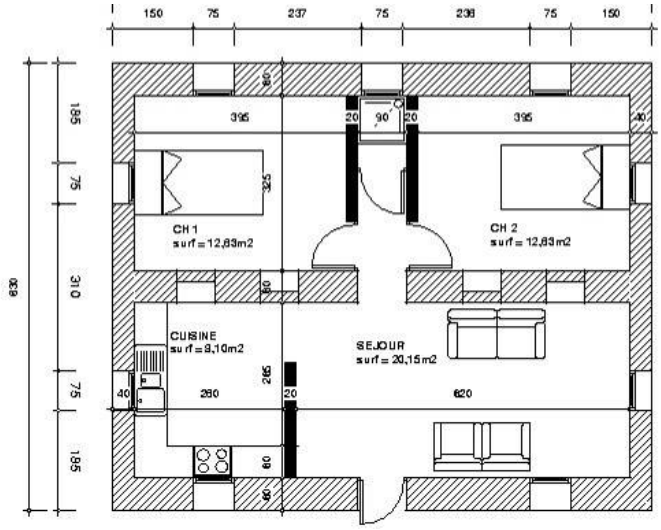

Figure 3: Ground plan of a standard two-bedroom VN house

Figure 4: Exterior view of a standard twin vault house

However, the fact that these standard, modular, designs exist does not imply that clients and builders have not modified, adapted, and improved the basic VN methods and structures. For example, many clients have asked to have the vaulted roof

transformed into a traditional Sahelian flat roof-terrace: this can easily be done by raising the side walls and filling in the sides of the vault with earth, bricks, and earth mortar. This also strengthens the vault and provides better thermal insulation. During the last building season (2005/2006), two-storey houses have been built (see Figure 5), with either external or internal stairs: the second storey vault being built on top of the flat roof-terrace formed by the ground floor vaults.

Figure 5 Two-storey house at Boromo, Burkina Faso

Many other examples have already arisen of adaptations and modifications of the VN technique, both by clients and builders, ranging from the very simple to the most sophisticated. Initial plans and dimensions have been changed, and improvements made to the layout and finishes, depending on clients' aspirations and resources. Such innovations enrich the scope of the VN principle, provided the basic technical principles of construction of the vaults are respected.

Examples of popular modifications of interiors include integrating an electrical supply into the masonry, cement rendering of the lower half of internal walls, and interior showers with cement floors and tiling.

Figure 6: Interior of a typical VN house

Modifications aimed at reducing the maintenance load inherent to all earth-built constructions include: use of a mixture of sand, mud, oil, and tar for external rendering and roofs, cement rendering of external surfaces, with a tar finish to the roof, and use of locally produced laterite bricks, or clay fired bricks, for the gable walls and the external courses of load-bearing walls.

It has also proved possible to combine the VN earth-built technique with more modern materials and techniques, such as concrete beams and pillars, to create larger internal volumes for communal buildings such as churches and community centres (see Figure 7).

Figure 7: Church at Petit-Bale, Burkina Faso, with concrete beams and pillars supporting vaults

2.3 Assimilation and apprenticeship

Training of VN apprentices takes place exclusively on-the-job, on VN building sites, under the guidance of a VN builder; familiar tools are used for the work, with no need for special devices or machinery. This method matches perfectly with deeply embedded cultural traditions, and encourages local and community involvement in construction. The time needed to learn how to build a VN house can range from 3 – 7 months, depending on the previous skills of the apprentice (a farmer with no prior building expertise will need more time than an experienced builder who just needs to learn the vault construction technique). Builders and apprentices who want to be trained in using the VN technique are asked to contact the project in Boromo, either in person or by phone. After coming to an agreement, board, lodging, and transport to the relevant building sites, will be provided (as well as a monthly payment of about 25,000 CFA francs, depending on experience, and progress made). At the end of the apprenticeship period, trained builders can either set themselves up as individual entrepreneurs (with help from the Association's network of contacts), or in agreement with the Association, become trainers themselves. It is also possible to divide time between these two activities.

The most significant criterion of the success of the project to date lies in the almost exponential growth, year on year, in the number of VN builders trained and apprentices in training (and in the corresponding number of vaults constructed). In the first year of formal existence of the project (2000), 7 vaults were built and 3 builders trained; during the current campaign (2006) 78 vaults have been built, and there are now 36 experienced VN builders (who also act as trainers), and a further 35 undergoing training.

2.4 Comparative costs

Making cost comparisons between VN house and the various alternatives (a traditional Sahelian house in adobe and timber, a 'modern' house in concrete blocks and a tin roof, a house with earth brick (adobe) walls and a tin roof…) is not a simple matter. For a start, the thermal insulation / comfort qualities are very different, with a VN house being far more comfortable and better insulated from heat and cold than one with a tin roof. And, in many parts of the Sahel, the traditional timber + earth flat roof-terrace is no longer an option, so such a comparison would be spurious. Furthermore, the costs of a VN house will vary from region to region – higher in urban than in rural zones, because of the differences in cost of transporting earth bricks to the sites, and within a region, and depending on climatic conditions (availability of water for making bricks and mortar being a key factor). Costs of materials are very different, with imported tin roofing materials and beams, and cement and concrete blocks, costing far more in cash than earth bricks made in a village environment; but this is partly balanced by the fact that a VN house will require around three times as many earth bricks as a tin roof house Furthermore, the proportion of labour : materials costs differ significantly from one method to another: a much higher proportion of the overall cost of a VN house is attributable to labour than for a house with a tin roof supported on sawn timber beams. And, in many rural areas of the Sahel, the labour costs may well lie outside any formal economic circuits, with neighbours trading time for building work with time for agricultural tasks. Finally, there are differences in ongoing maintenance costs, with earth roof VN houses requiring some maintenance and re-rendering every two years or so, after the end of the rainy season (however, the skills needed for such maintenance are well-known, having been practised for generations on the traditional flat roof houses, and on communal buildings such as mosques).

In a detailed evaluation of comparative costs of VN methods with the alternatives, in Burkina Faso, Wyss [7] concludes that a VN house in a rural zone can be up to 30% less expensive, on average, than an earth wall + tin roof house of the same size; however, in an urban milieu this advantage is lost, because of the cost of transporting the bricks from outside. Overall, he concludes that the advantages of the VN method lies not in the fact that it may be 'cheaper' than and adobe / tin roof or a concrete / tin roof building, but that:

- the raw materials can be extracted, made, and transported locally;
- the client (family, neighbours) can, if required, provide a significant proportion of the labour;
- payment for labour can, if needed, be provided on a barter basis, outside formal economic circuits.

And, for sure, the VN house is far comfier and more agreeable to live in than one with a corrugated iron roof!

3. CONSTRUCTION METHODS

3.1 Foundations

Depending on the properties of the ground and the site of the building, foundations can vary from 20 to 45 cm deep. They are filled with rocks, bound with an ordinary earth mortar. In sites where there may be strong flows of surface water during the rainy season, the foundations may be raised 10 – 15 cm above ground level.

3.2 Load-bearing walls

Load-bearing walls which carry the vault are around 60 cm thick (depending on the dimensions of the brick moulds being used), and are made up of rows of super-imposed mud bricks. Each course is made up of a row of bricks laid lengthwise alongside a row laid width wise, using an earth mortar. The orientation of the bricks alternates with each course.

Recesses and openings are built into the thickness of the walls, for doors, windows, cupboards, alcoves, and shelving. These are headed with arched lintels (built over oil drums as a temporary support); their use can be modified according to the needs of the owner. These are built before construction of the main vaults starts.

3.3 Gable walls

Gable walls are built in courses of bricks laid lengthwise, and are around 40 cm thick. They are raised to lean slightly inwards (by around 1.5 cm for each metre of height).

3.4 Vault construction

The vaults are built without any shuttering. Firstly, flat bricks (24cm X 12 cm X 4 cm) are made from good quality earth (for example that traditionally used for building granaries). These are then used to build the vault, supported on the load-bearing walls. The bricklayer, using a mortar made from the same earth, starts the vault by laying the first courses against one of the gable walls

A cable made of six steel wires coiled together is stretched between the two gable walls, at the height of the base of the vault. This defines the central axis of the vault, and a cord fixed to a sliding ring on the cable acts as a guide to ensure that the bricklayer maintains a constant radius for the vault (see Figure 8). The upper section of the vault is transformed empirically from a semi-circular to an ogival shape, by the addition of a finger's length to the radius for each succeeding course of bricks over 70 degrees.

Figure 8: Vault construction using the guide cable

The builder alternates work on the top of the vault, which requires some waiting time between each course for the mortar to dry, and the sides, which are easier to construct. Buttresses are formed on the completed vaults by raising the side walls by 8 to 10 courses of large bricks, and by filling the gap so created with plain earth.

Finally, the roof is water-proofed, using plastic sheeting (locally manufactured *FasoPlast*, costing around 400 CFA francs / square metre), over a smooth coat of mud mortar. The sheeting is then covered with a rendering around five cm. deep of enriched mud mortar (using traditional adjuvants), which both protects the plastic from damage by the sun, and provides additional protection against heavy rains.

3.5 VN Interiors

Depending on the resources and the tastes of the owner, renderings and floors of cement mortar might replace those made with earth. Coloured or plain lime washes are inexpensive to apply to the interior walls, and help reduce insect infestation. Installation of an electrical supply and water pipes during construction is straightforward.

5. THE AVN PROGRAMME AND PROJECTIONS

Since the start of the AVN's *Earth roofs in the Sahel* programme in 2000, some 200 vaults have been built; 80% of these are in low-cost rural homes (an average VN house has two vaults); however, some larger buildings have been erected, including a mosque, a church, and several small hotels. In the project zones in Burkina Faso, there is now clear evidence of an emerging market for VN homes, with the more committed VN builders setting up as entrepreneurs on their own account. Furthermore, builders from Mali and Togo have been trained in the VN methods in Burkina Faso, and have now returned home to start their own projects.

The challenge for the coming years is to design and implement a strategy which will make possible the move from a successful small-scale project to something much bigger. The accumulated project experience since 1999 has shown that VN houses are affordable, safe, comfortable, durable, and aesthetically pleasing, and that the VN technique can be adapted to individual clients' requirements. They represent a real, cost-effective, ecologically sound and sustainable alternative to the use of imported timber and sheet metal roofing. As such, it is clear that there are many poor rural and peri-urban communities throughout the Sahel region who could benefit from discovering and adapting the VN technique to their own situations. Some early steps have already been taken in this direction (e.g. a few builders from Mali and Togo have recently been trained on VN sites in Burkina Faso), but much more needs to be done, on a much bigger scale. And, of course, some of the cultural barriers to the use of earth / adobe for building will need to be addressed – in some circles, notably amongst middle-class families in West Africa, earth construction is seen as primitive, lacking the 'modern' connotations of construction *en dur* (i.e. concrete blocks, cement, metal sheeting …). And some public authorities and ministries have actually banned the use of earth construction for buildings such as schools and clinics, even in rural areas – this despite the fact that most of the traditional mosques in the Sahel are built entirely in earth, and have been in use for decades, if not centuries, as long as they are properly maintained.

In the medium-term, over the next six years, a reasonable extrapolation based on the progress made in the last six years, would indicate that by 2012 the total number of trained VN builders would be around 250, and the total number of vaults built around 2,250. However, these projections assume a continuation of the present rather modest strategy of the opening up of a few new action zones each year, with training of new builders being reliant on actual building sites and the inputs of trained VN master builders. To bring the benefits of VN housing to the poor rural and urban families who most need them will require a scaling up of the current VN strategy, and the involvement of a wider range of partners on the ground (government departments,

NGO's, private and state companies, affiliated associations…), and in a wider range of countries and regions of the Sahel. The Association is currently engaged in studying different models for this scaling up process (e.g. dissemination through word of mouth and informal contacts, a devolved but structured and controlled approach by 'franchised' partners, a totally centralised approach organised uniquely through the VN organisation, etc.). On a 20-year horizon, if successful scaling-up can be achieved, we would hope to see, cumulatively, something like 10,000 trained VN builders, and some 400,000 homes built in the Sahel regions by 2030.

Finally, it is clear from recent enquiries coming from outside the Sahel that the Association will need to investigate the applicability of the VN methods to different socio-economic contexts (e.g. in the Maghreb, not only for social housing, but also for agricultural buildings, and residential villas and hotels), and to different climatic conditions (e.g. tropical countries such as Madagascar, southern Benin, and Sao Tome et Principe). Studies analysing the economic and technical factors concerning the adaptation of the VN methods to these new contexts will need to be undertaken in the future before an appropriate response can be made to such enquiries.

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ANNEXE : VN BUILDING GUIDELINES

(1) FOUNDATIONS

Foundations are extremely important and must never be neglected

- ✓ For foundations for lateral walls (60 cm wide) supporting vaults, in normal earth, a trench 60 cm deep and 70 cm wide must be dug
- ✓ For foundations for gable end walls (40 cm wide), in normal earth, a trench 60 cm deep and 40 cm wide must be dug
- ✓ For interior partition walls (20 cm wide), a trench 40 cm deep is sufficient
- ✓ These depths can vary up or down depending on the type of ground (sand, laterite, etc.)
- ✓ The foundations must be completely and carefully filled with large and medium size rocks, and banco
- ✓ For normal foundations (60 cm deep, ground neither too soft nor too hard), estimate one cartload of rocks for every 2 square metres of floor space
- ✓ For two-storey buildings, increase the depth of the foundations.

(2) CONSTRUCTION

- ✓ Load-bearing walls supporting the vault must be around 60 cm wide, built in alternate rows of large bricks (one row laid widthwise, the next lengthwise); the mud bricks normally made in most villages (more or less 18 cm high) can be used.
- ✓ The height of these walls should be 6 to 11 rows (1,40 m – 2 m) before the start of the vault, depending on the means and requirements of the client
- ✓ The lateral walls should be continued with 5 – 9 rows of large bricks once the vault is completed, and the gap each side between these raised walls and the sides of the vault should be filled carefully to form a more or less flat roof (to use as a roof terrace, and to give improved weatherproofing and strength)
- ✓ The gable end walls (around 38 - 40 cm wide) should be built in large bricks laid lengthwise; the walls should slope inwards slightly (1 cm per metre height)
- ✓ The partition walls (around 20 cm wide) are built in large bricks laid widthwise
- ✓ Clients are advised to include many openings with vaulted lintels (use an oil drum as a former) of a maximum width of 80 cm; it is feasible to have a 75 cm opening for every running metre of external lateral walls, and 70 cm openings for every 80 cm of partition wall, and the openings can be used as doorways, or be half-closed to form windows or cupboards. Inclusion of such openings in the original structure also allows for later flexibility and extension.

(3) DIMENSIONS

- ✓ The internal width of the vault (and hence the floor between the lateral walls) must not exceed 3,25 metres
- ✓ The length of the building (up to 12 m maximum) and the number of vaults alongside each other depends on the needs and means of the client

- ✓ The internal height of the vaults can vary from 2,50 m to 3,50 m depending on the client's needs
- ✓ By lowering the internal floor level by 20 cm (one step) internal height can be increased, and extra earth made available for construction.
- ✓ Two-storey buildings with an internal staircase can be built, but only under the supervision of an experienced VN builder

(4) BUILDING MATERIALS

- ✓ For all walls: good quality banco and large bricks (of the traditional type found in most villages)
- ✓ For the vaults : banco and high quality small bricks (25 cm X 12 cm X 4cm), made under the supervision of the VN builder
- ✓ If the additional costs can be met by the client, walls can be built with laterite bricks, or a mixture of laterite and mud bricks

(5) RENDERING AND MAINTENANCE

- ✓ A layer of plastic sheeting (e.g. *FasoPlast*) must be included under the last layer of rendering on the roof; this guarantees a weatherproof finish which complements the external rendering
- ✓ The plastic sheeting must never be left revealed, as the sunlight will damage it, and must be covered by a final coat of earth rendering
- ✓ All external renderings must be checked annually and renovated as needed, as is the custom for all earth buildings
- ✓ Many traditional adjuvants can be included in the external earth renderings to increase waterproofing
- ✓ For clients who want this, final renderings in cement or tar can be used to minimise the need for annual maintenance.

(6) ADVICE TO CLIENTS

- ✓ To build a VN house, you need to use an experienced VN builder who has already constructed several vaults
- ✓ You must not try to economise on the width of the walls, the depth of the foundations, and the quality of the earth used
- ✓ You must carry out annual checks and maintenance of external renderings, especially of the roof
- ✓ A house can be made of two vaults side-by-side, thus economising on one load-bearing wall; two-storey vaulted houses can be built.
- ✓ A house can be built little by little, over a period of several years

- ✓ A flat terrace roof can be incorporated into the design
- ✓ Clients are advised to start collecting bricks and building as early as possible (October, November), to benefit from the availability of water
- ✓ Take care over the choice of your site and the proper evacuation of rainwater
- ✓ Load-bearing walls can be built during the rainy season, especially if they are constructed from laterite bricks.

(7) EXAMPLE ESTIMATE

Here is an estimate of materials needed and labour time for a house of 52 square metres floor space, with 2 bedrooms, 1 shower, and 1 living room / kitchen (about the same dimensions as a house needing 44 corrugated metal roofing sheets):

Building materials
- 30 barrows of rocks for foundations
- 4300 large bricks (38cm X 18 cm X 18 cm)
- 130 barrows of ordinary earth for the walls
- 70 barrows of high quality earth for the small bricks and vault
- 150 barrels of water

Labour (assuming all materials are on site)
- 26 working days for two VN builders
- 26 working days for two VN apprentices
- 26 working days for 5 labourers