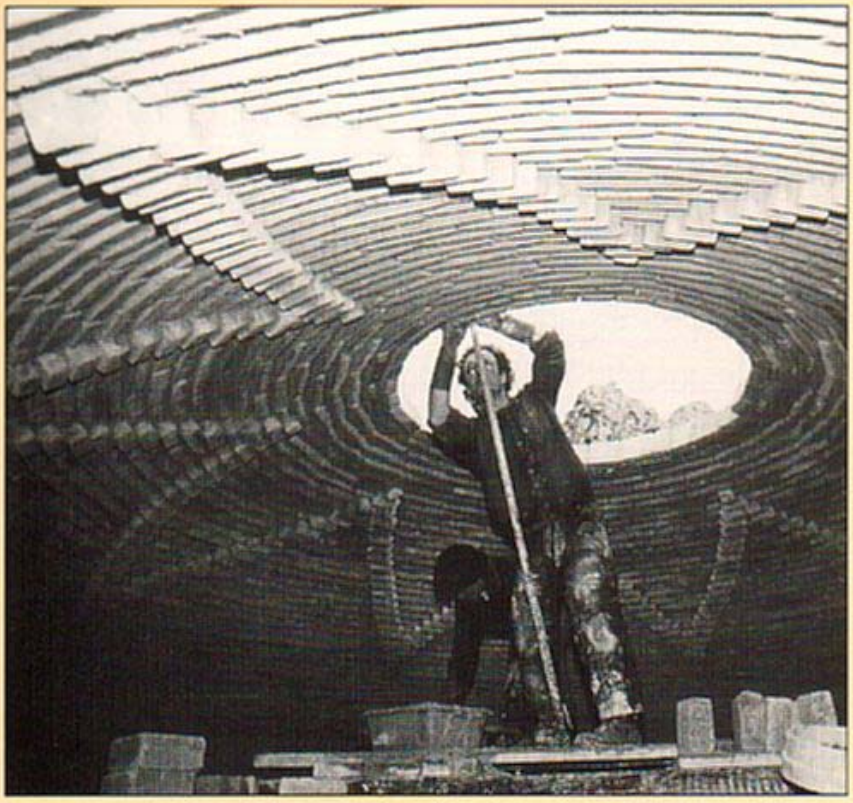
SKAT

CRATerre-EAG

The Basics of

Building with Arches, Vaults and Cupolas

The possibilities and limitations of building with arches, vaults and cupolas for decision-makers and building professionals



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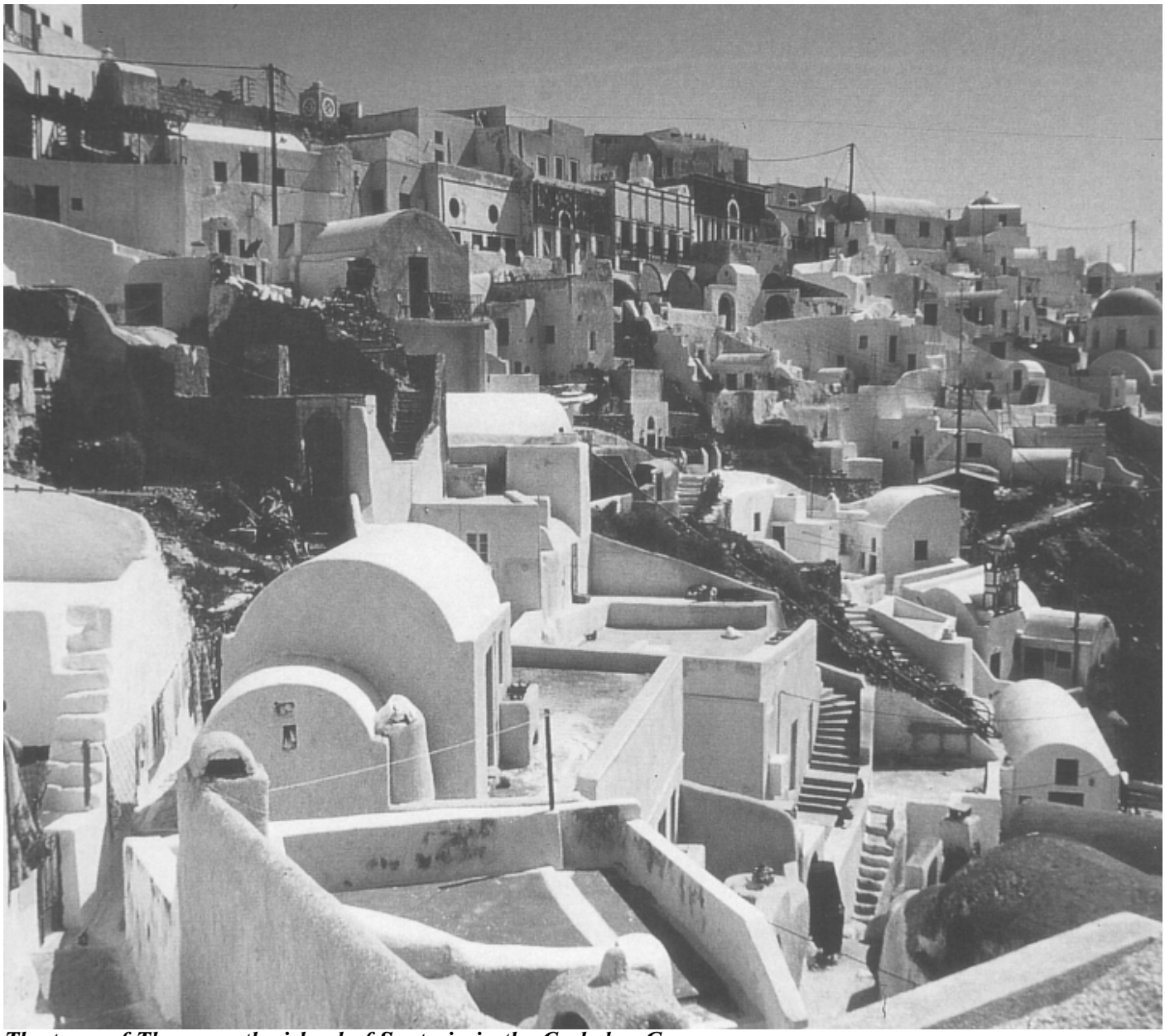

The town of Thera, on the island of Santorin in the Cyclades, Greece

The Basics of Building with Arches, Vaults and Cupolas

A SKAT publication, Swiss Center for Development Cooperation in Technology and Management, 1994.

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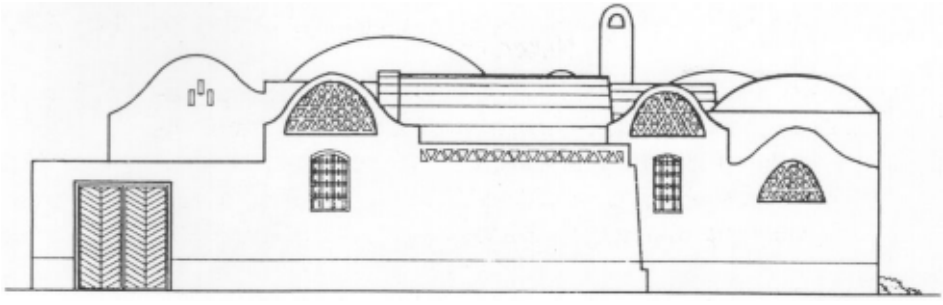


Project of the architect Hassan Fathy, villa at Fayoum, Egypt, 1984

ARCHES, VAULTS AND CUPOLAS

A thousand-year old technology

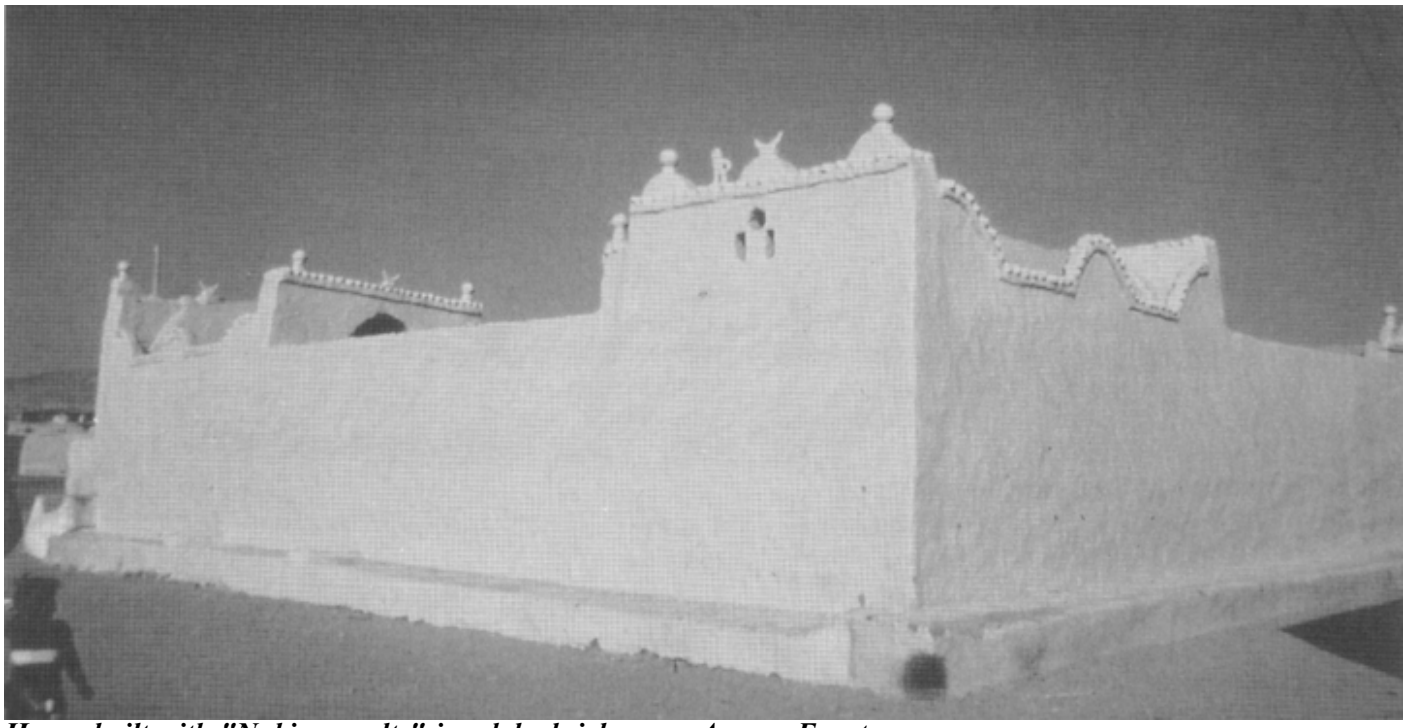
The use of arch, vault and cupola building systems in construction can be traced back to most ancient times. As early as the 3rd millenium BC, they were very widely used in the countries of the Middle East and Egypt.
Arches, vaults and cupolas were also fairly widely used by Roman, Sassanid and Byzantine builders before being adopted in many regions of Europe.
Very many applications also emerged in North Africa, the Sudan-Sahel belt of Africa, as well as in the northern regions of China.
Many of these countries still boast a rich heritage of this kind of building, both in urban and in rural areas. In many cases, building them is still a living tradition, well suited to modern popular housing needs.

Diversity

The numerous types of arches, vaults and cupolas allow a great variety of architectural models.
As a result, the technology can adapt to the most varied climatic conditions: zones which are arid or rainy, cold or hot.
Although arches, vaults and cupolas are traditionally used to cover limited spaces, they are perfectly well-suited to build much larger spaces, up to tens of meters. Thus they can meet the needs of any building programme, public or private, low-cost or quality housing, granaries, warehouses, shops, schools, public, religious buildings, etc.

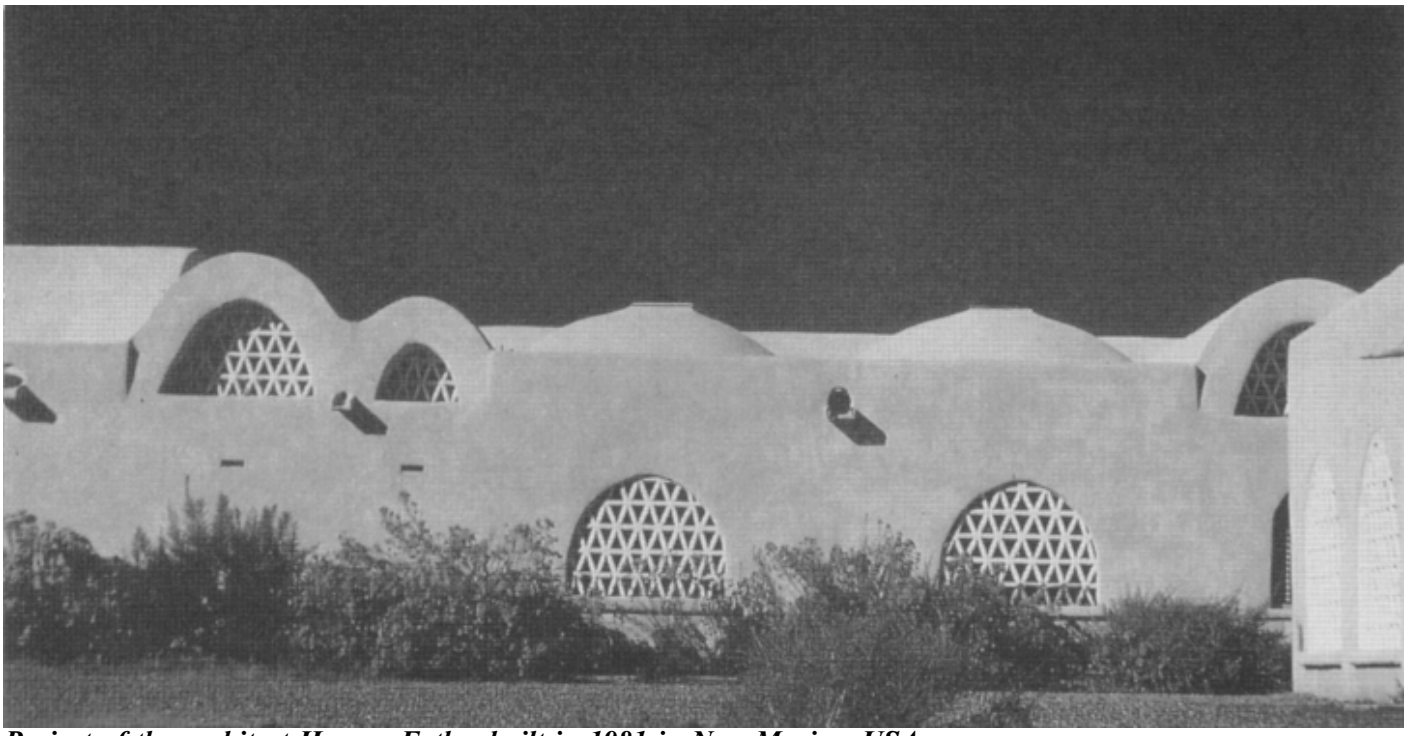
Recent projects

Forgotten by the formal building sector since the appearance of concrete, arches, vaults and cupolas were rediscovered in the 40's by the Egyptian architect, Hassan Fathy, who found inspiration in the popular Nubian tradition for the design and construction of the village of New Gourna.
The international success of this project, and of other Hassan Fathy achievements, rekindled a renewal of interest amongst architects.
Realizing the significant potential of these architectural models, some development project managers have re-launched the use of arches, vaults and cupolas.
These programmes, have enabled the construction of many buildings meeting the varied needs of different countries.



House built with "Nubian vaults" in adobe bricks near Aswan, Egypt

TRADITION, PRESENT AND FUTURE



Project of the architect Hassan Fathy, built in 1981 in New Mexico, USA

Suitability

Arches, vaults and cupolas can often provide a good solution for covering all kinds of buildings of all sizes. However, their acceptability and suitability to genuine needs and local climatic conditions cannot always be taken for granted.

This means that preliminary surveys are required. These enable one to choose the correct option and select suitable technical solutions.

In order to ensure that structures are well designed and well built, specialized training must be given at all levels: design, engineering and construction.

Mastering the technology

The experience acquired over the last twenty years has allowed the design and construction of buildings using arch, vault and cupola structures to be mastered once again.

The technology is now used in several areas of the world: the Sahel belt of Africa, the Near and the Middle East, India, Central America.

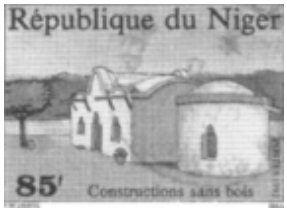
Initially launched in Niger, the "Woodless Construction" programme suggests simple technical solutions, well-suited to the local context, and follows a policy of research and training which ensures a major impact amongst local people.

Winner of the "Habitat" Award 1992, this programme is now spreading to other countries of the Sahel.

Research and development

Even though arches, vaults and cupolas are already well known, research and development programmes are being carried out, mainly in four areas:

1 - systematic identification of models and types, and the various ways of using them ;
2 - suitable tools to substitute for the know-how of traditional builders ;
3 - perfecting simplified methods of calculation ;
4 - techniques to prevent rainwater infiltration: water-proofing, run-off, surface maintenance.



ARCHES, VAULTS AND CUPOLAS

Deficiency of traditional roofs

In many countries, good quality wood required for the construction of traditional roofs is no longer available in sufficient quantities. This results in the use of poor quality wood, imports, or even turning to conventional modern techniques such as woodworks covered with corrugated iron sheets or concrete slabs.
Gradually these conventional modern techniques have emerged as the only alternative to traditional ones.

Disadvantages of conventional modern technologies

Industrial products such as asbestos sheets and corrugated iron are not always well suited to local conditions (heat, cold, noise, appearance, etc.)
Often imported or even produced in centralized units, they encourage low skill levels more than job creation.
Building systems based on the use of reinforced concrete consume large amounts of expensive materials such as cement, steel, timber for formworks, as well as sand and gravel which are not always locally available. This places them out of reach of the vast majority of local inhabitants.

Research centre, Dakar, Senegal

An alternative

Traditional techniques, adaptations of these, or newly imported techniques do not always provide a solution to roofing needs in harmony with local conditions: cultural, climatic or even economic.
As a result, alternative roofing solutions are needed. Building with arches, vaults and cupolas is, in many instances, one of these solutions.
Their numerous variations and wide range of architectural solutions enable them to be adapted to very diverse situations.

Information and reception centre of Auroville, India; International Hassan Fathy Award 1993

Advantages of arches, vaults and cupolas

The materials used for the construction of arches, vaults and cupolas can be the same as those used for walls and can be found or produced locally. Construction is therefore less expensive, creates jobs and allows foreign currency savings.
There is no use of wood, which also totally eliminates the risks of fire.
The massive nature of these structures provides good heat storage capacity and delay in heat transmission, meeting comfort requirements, especially in dry climate regions.
This mass also gives good sound insulation.

ADVANTAGES AND POSSIBILITIES

Economic considerations

The cost of buildings using arches, vaults and cupolas varies according to the materials employed, the complexity of the design and of the construction technique, the size of the structures, and the surface protection used.

However, buildings employing sun-dried earth bricks (adobe) and protected with an earth render can be built at a lower cost than traditional buildings of a similar standard.

In general, arches, vaults and cupolas made from water-resistant materials and protected by durable water-proofing cost more than simple buildings covered with roof sheeting, but remain less expensive than buildings with reinforced concrete slab roofs.

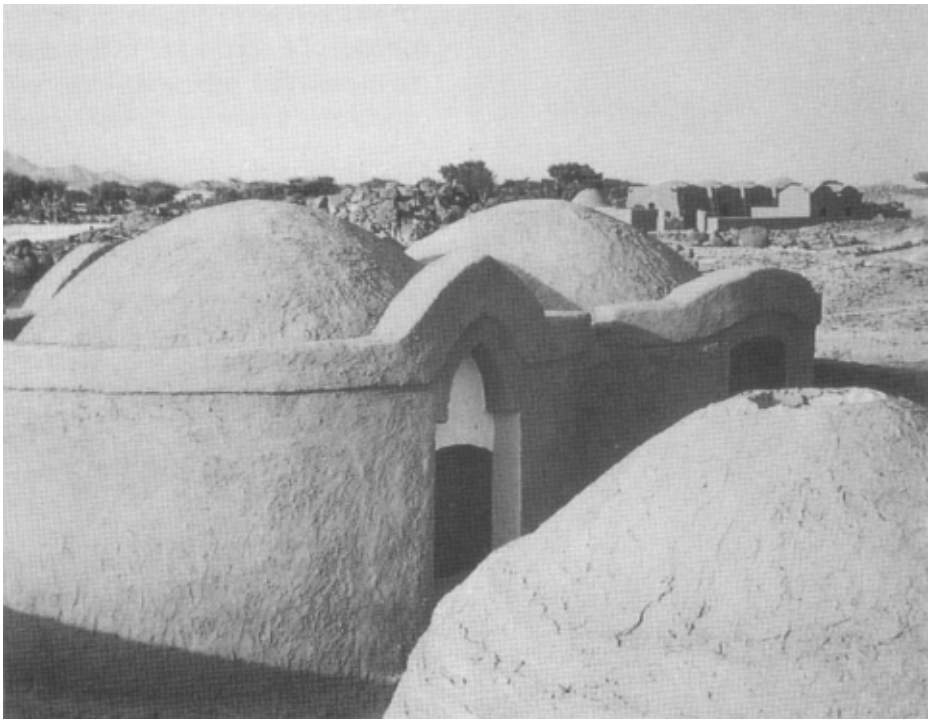
Job creation

Building with arches, vaults and cupolas is highly labour intensive. Therefore, the technology has great job creation potential, not only with regard to construction, but also with regard to building materials production.

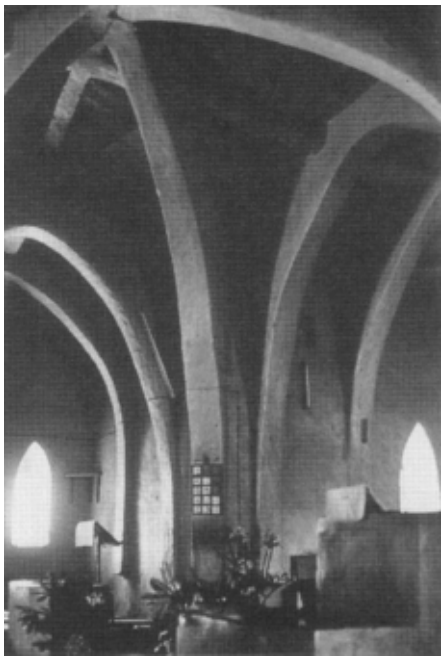
Foreign currency savings

The basic materials are generally available on site, and little power is required for processing them. Significant foreign currency savings are possible. Transport costs are also reduced.

The investment in site equipment, centering, compass, scaffolding, is generally very small, and most of these can be manufactured locally without any major difficulty.



"Woodless construction" project in Niger: simple but adapted structures



Crossed arches, Zaria, Nigeria

Great aesthetic potential

The many possibilities of forms, sizes, combinations of different elements and types of finishing enable highly attractive spaces to be created. Thus arches, vaults and cupolas can be used not only for low-cost housing programmes, but also for high quality, luxury dwellings.

Limitations of use

Some local conditions can limit the benefits of building with arches, vaults and cupolas:

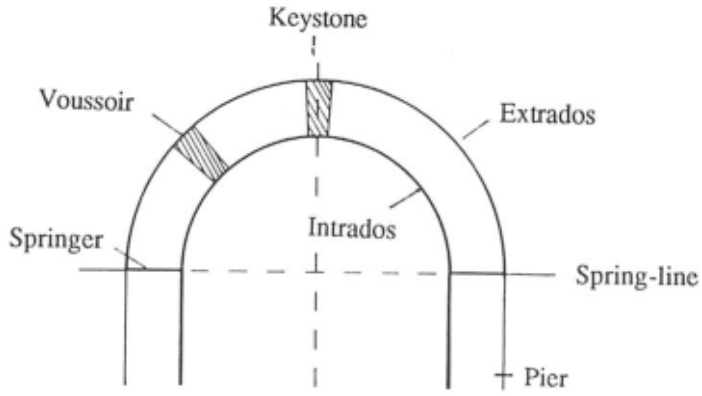
- rejection by the inhabitants for cultural reasons,
- high cost of labour,
- high cost of suitable building materials,
- use in earthquake areas requires special care,
- lack of building norms.

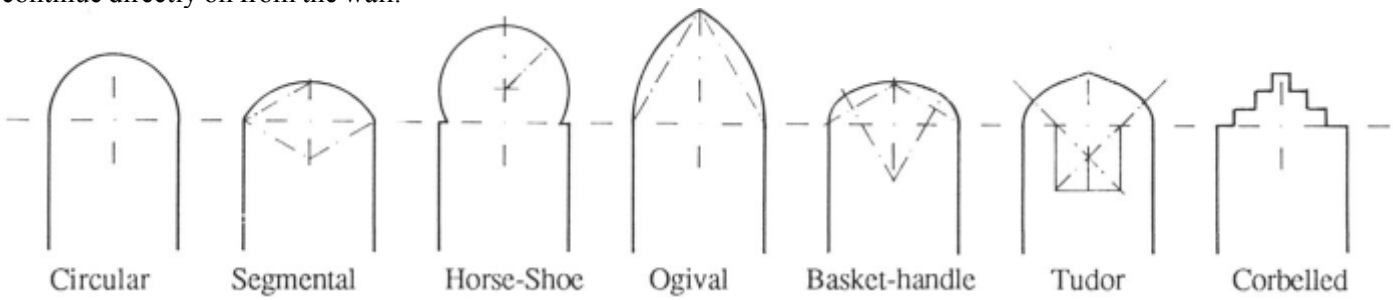
The technology must be adjusted to a given context and the techniques must be mastered, to warrant the advantages of using arches, vaults and cupolas.

ARCHES AND THEIR USES

Forms of arches

There are many shapes of arches. These are mainly characterized by the curve of the intrados and the ratio of height to span.
Most arches are connected to the wall by the extrados. The corbel arch, built using courses gradually jutting further out, and monolithic arches, whether poured, tamped or cut out, have no extrados and continue directly on from the wall.



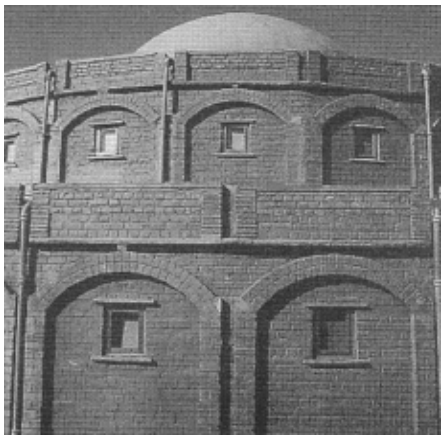


Varied uses of arches

The main function of an arch is to bridge an opening in a wall.
By juxtaposing and repeating arches resting on pillars, one can obtain arcades (1), which allow one to create very open covered spaces.
Arcature, or blind arches (2), can be used to lighten the masonry structure or simply for decorative purposes.

(1)

A partition arch (3) serves as a loadbearing element in a large room by supporting roofing elements of restricted length, joists, purlins or even vaults or cupolas.
An arch can serve directly as the springer of a cupola (4). In this case the forms of the arch and of the cupola are closely interlinked.



(2)

(3)

(4)

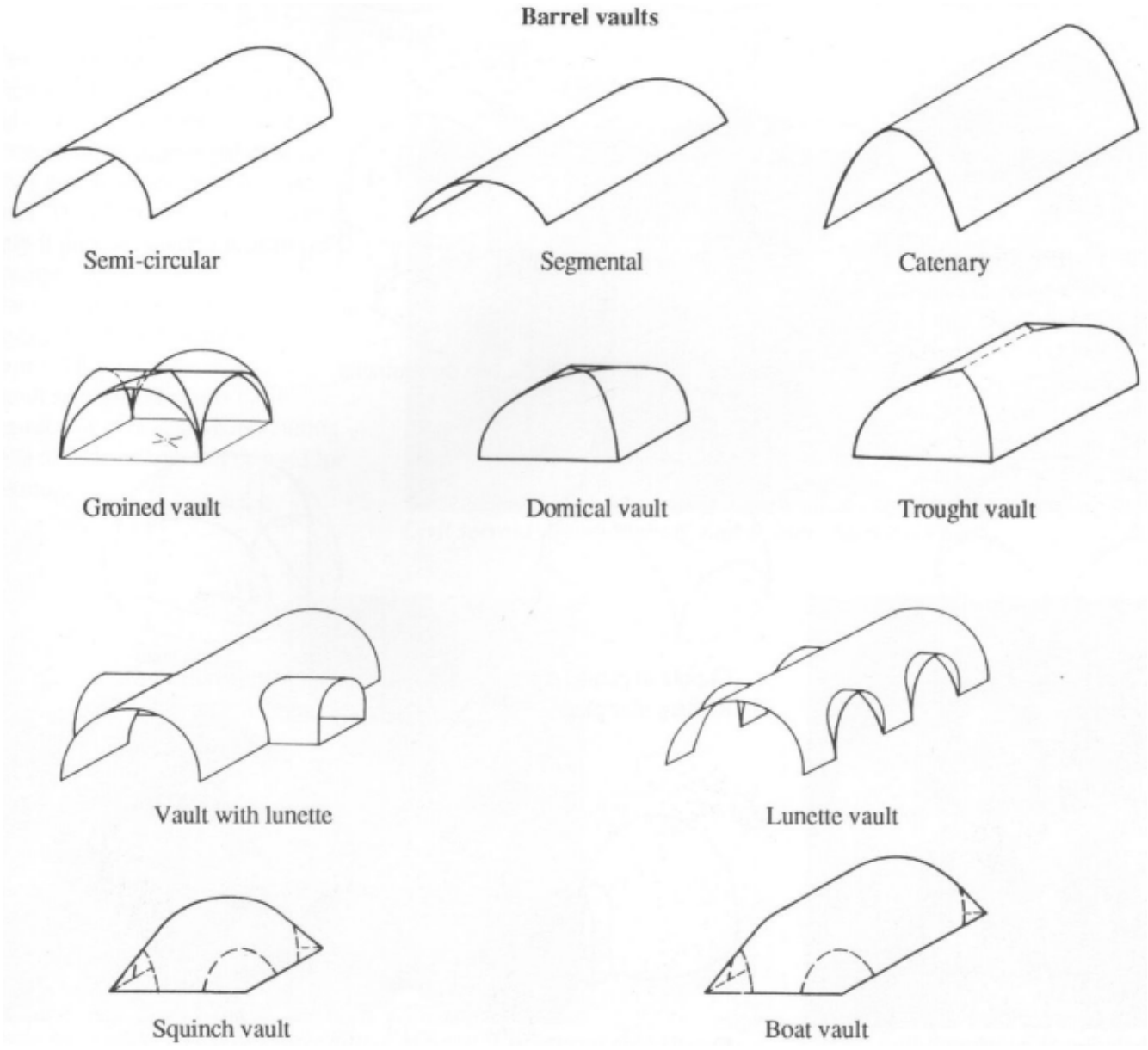
VAULTS

Forms of vaults

There are a great many forms of vault. The simplest are barrel vaults which in fact consist of a succession of identical arches. Barrel vaults can have steeper or flatter profiles: semi-circular, segmental, ogival. etc. The catenary vault is very common as its form gives maximum stability for a minimum use of material.

Combining two barrel vaults with the same profile allows two other types to be defined: the "groined vault" and the "Dominical vault". By prolonging one of the two barrel vaults, the "Dominical vault" becomes a "trough vault". Combining barrel vaults with different profiles forms a "lunette vault".

A "Dominical vault", the ribs of which are rounded in the form of cones starting from the corners, becomes a "squinch vault". Similarly the "trough vault" can evolve into a "boat vault".



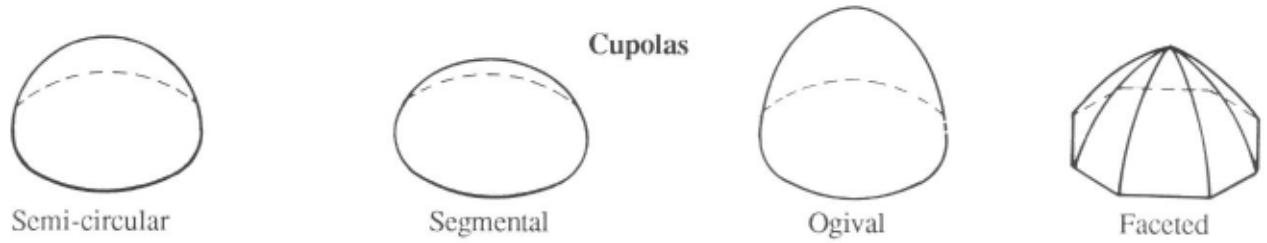
CUPOLAS

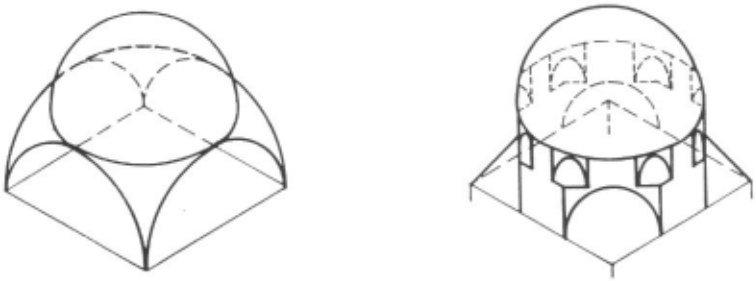
Forms of cupolas

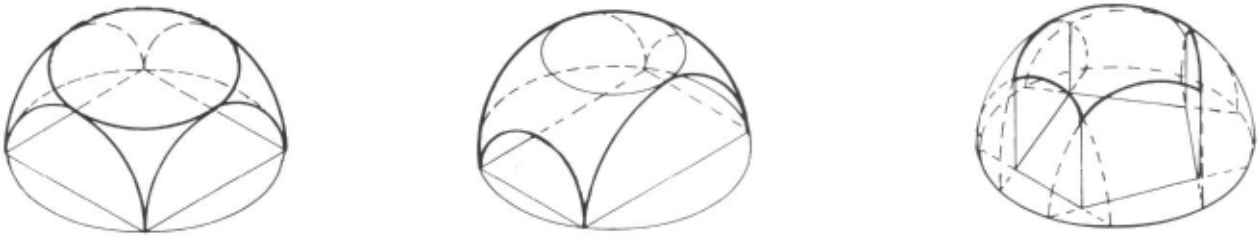
Cupolas are obtained by rotating an arch, except for faceted cupolas which more closely resemble the Dominical vault. A cupola can be semi-circular, segmental, ogival, conical, etc.

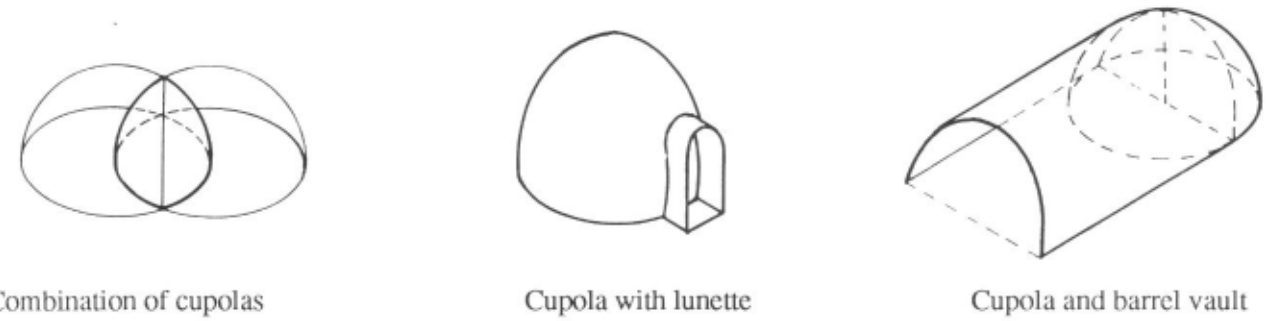
Cupolas are circular in plan. They can, however, be used to cover square or rectangular rooms by using pendentives or squinches. Cupolas on pendentives can be used to cover any kind of polygonal shape in plan.

It is possible to combine several cupolas or to combine cupolas with vaults.



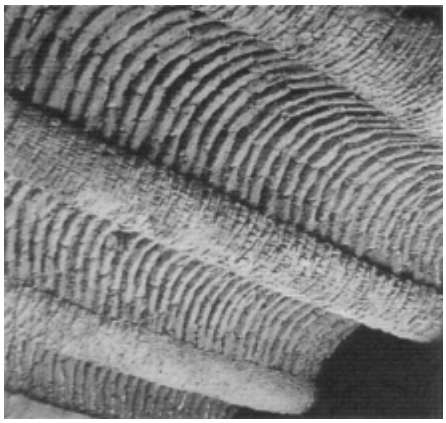






USES OF VAULTS AND CUPOLAS

Rural housing near Lake Titicaca, Bolivia



Adobe vaulting cells

Varied uses

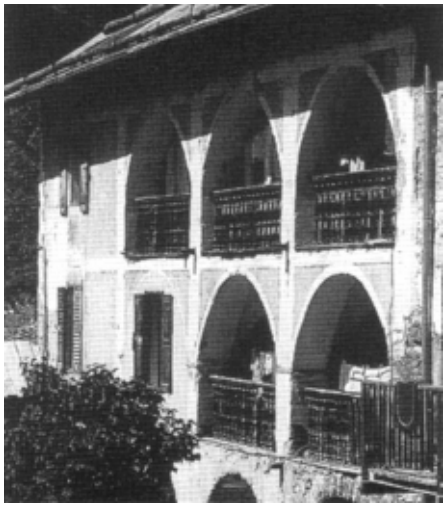
Vaults and cupolas cover spaces either with or without recourse to walls or other supporting structures. They are, however, merely structures. They become a roof-covering only if they are given a waterproof coating.

Flat or slanted roofs and flooring can be easily obtained by infilling the rounded forms.

Small span barrel vaults built between girders, known as vaulting cells or jack arches, can be used for flooring.

Civil servant accomodation, Kamboincé, Burkina Faso

Stone barn with flat-stone roof, Causse Méjean, France



Farm building using several levels of ribbed vaults, Queyras, France

DEVELOPMENT PROJECTS

Housing and development

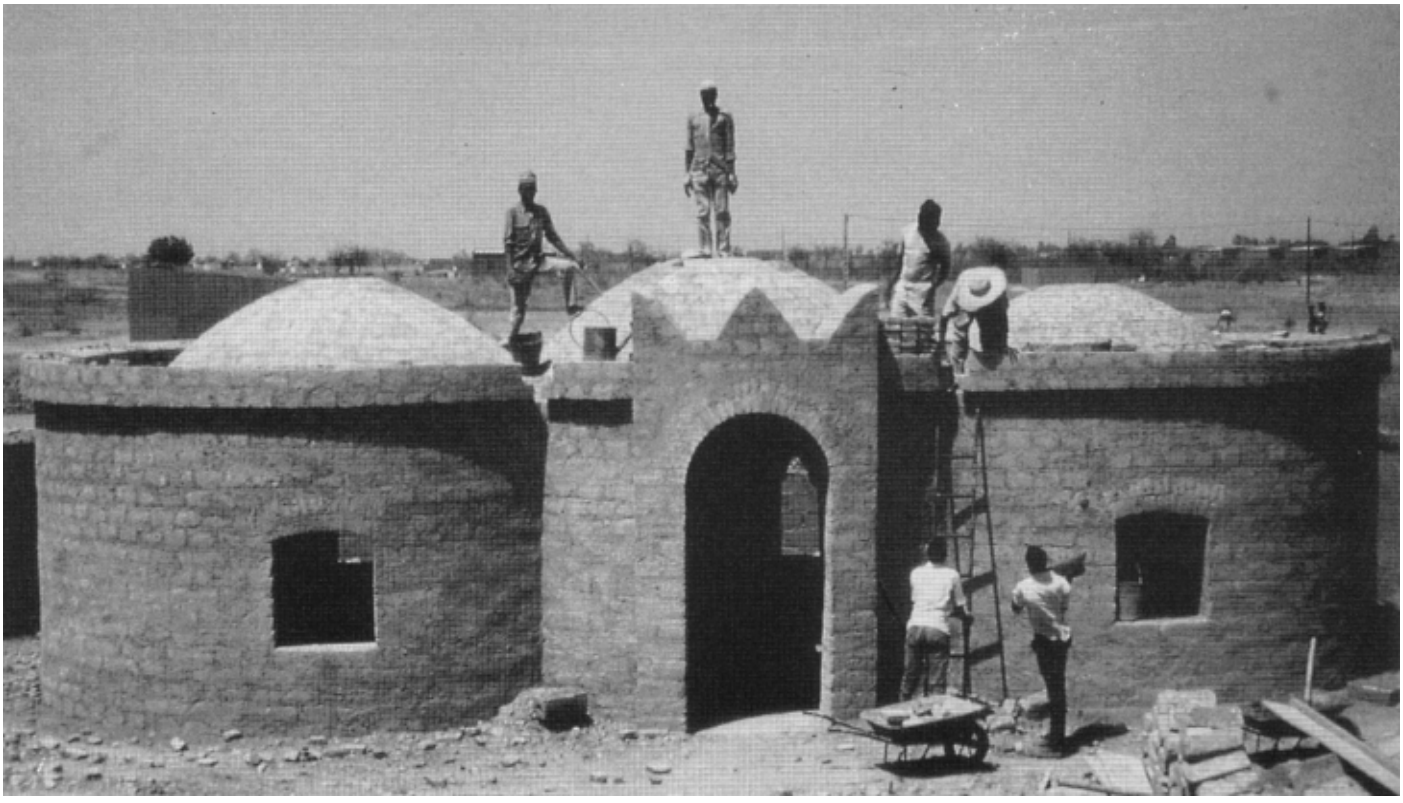
In the context of applying a development policy, programmes implemented by government and non-government organizations aim not only to produce buildings, but also to have a spin-off effect on people's socio-economic situation.
Apart from the requirements of housing programmes, job creation and the preferential use of local raw and building materials are the main technical objectives that building with arches, vaults and cupolas can meet perfectly.

Preliminary actions

Preliminary surveys, as well as various stages of experimentation and training, will ensure a successful implementation.
Where no tradition exists, preliminary surveys represent a significant investment. As a result, organizations play a major role, as sufficiently wide programmes enable this investment to be amortized.

Implementation

The implementation of a building programme should always form part of a development approach and strategy.
In all cases, the professional training which is given during project implementation is an asset which can benefit the whole community.
Involving local tradesmen, entrepreneurs, architects, engineers and draftmen, ensures the possibility of spontaneous and correct replication of the building models proposed and their dissemination.



Spontaneous replication of models is a sign of a development project's success; "Woodless construction" programme, Niger

BUILDING MARKET

Focus on building materials

Building with arches, vaults and cupolas highlights the potential of the building materials used. Demonstration structures and designs allow their quality to be illustrated and their credibility amongst the public to be reinforced. This can strongly counterbalance resistance to new materials in the marketplace.

Focus on enterprises

Because it calls for technical knowledge and skills, which non-professionals always find impressive, it also focuses on the enterprises involved and confers upon them a favourable quality image.

Quality

The quality of a building depends on the quality of the basic materials and of the building work. The durability of the structure will be linked to surface protection or water-proofing being carried out well.

To ensure the quality and durability of the building, the contractor should carefully control site supplies and work. In addition, the client should be informed about any required maintenance of the surface protection, frequency and technique.

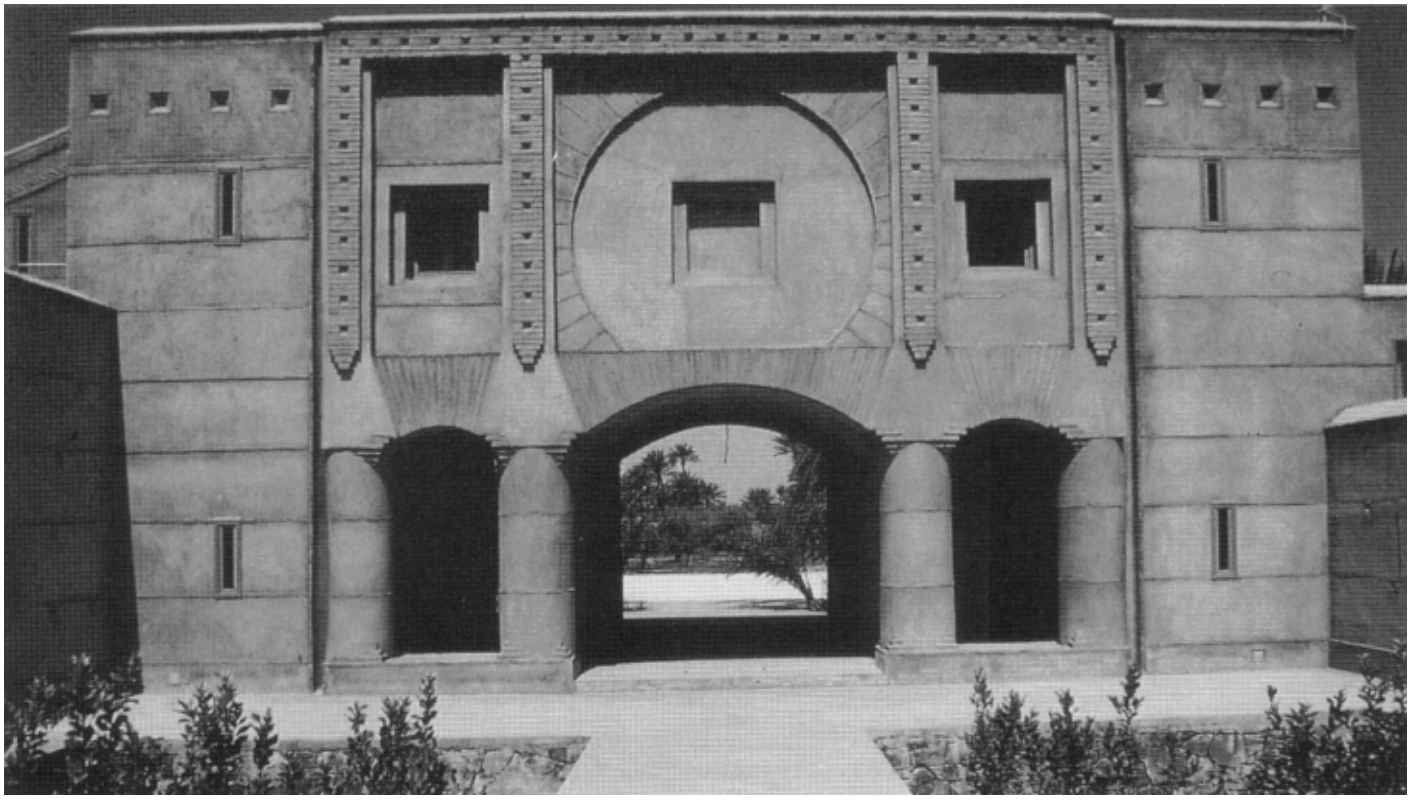
New markets

Launching into building with arches, vaults and cupolas can open new markets, public or private, especially if the launch takes place in conjunction with pilot promotion programmes run by organizations.

Investment

Investment is generally very low as the equipment required is simple and can be manufactured locally.

On the other hand, in order to ensure a good quality of his achievements, the entrepreneur will have to invest in training his employees. This investment will be balanced by the quality of the realization.



An attractive technology; private house, Marrakesh, Morocco

KEY QUESTIONS

If you are interested in building with arches, vaults and cupolas, you should be aware of the implications that follow on, with regard to:

- acceptability of architectural models,
- building materials,
- building skills,
- costs, management and investment .

10 key questions

1 - Is there a demand for an alternative roofing solution or for an improvement in traditional techniques of building with arches, vaults and cupolas?

2 - Do you think the people would accept buildings made with arches, vaults and cupolas?

3 - Are suitable building materials available locally or can they be produced?

4 - Do you have a suitable solution for surface protection or water-proofing?

5 - Are you aware that all types of roofing systems need periodical maintenance?

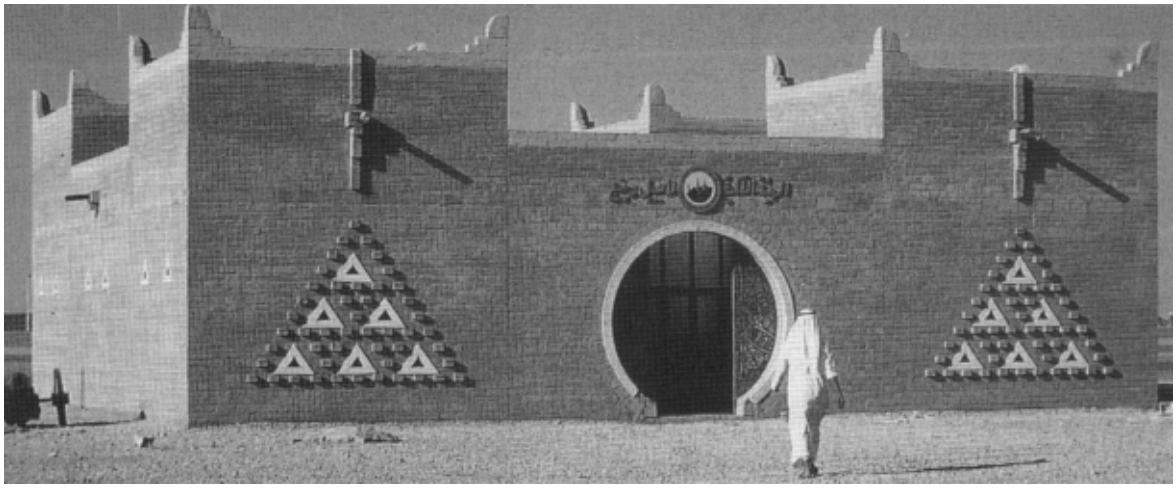
6 - Do you realize that it may be necessary to revise your building methods as a whole?

7 - Is your region prone to specific building problems like earthquakes or swelling soils ?

8 - Are you prepared to make an investment in equipment and in technical surveys?

9 - Are you prepared to pay particular attention to training?

10 - Do you know where you can find technical and training support?



Exhibition centre, Janadriyah, Saudi Arabia

RECOMMENDATIONS

If by assessing the ten key questions you conclude that there is a potential to construct arches, vaults or cupolas, it is recommended to make a fine-tuned feasibility study. This should be made also in order to elaborate a programme of activities ensuring a successful building with arches, vaults and cupolas.

Feasibility study

It should be conducted on the following main aspects:

1 - Socio-cultural:	demand analysis, acceptability amongst local inhabitants,
2 - Economical:	living standards, costs, credit, market, loans,
3 - Technical:	structural and surface protection materials, statics, norms in force,
4 - Climatic and geographical:	weather, environment, natural calamaties,
5 - Institutional / entrepreneurial:	organisations, policies, capability and means,
6 - Skill and know-how:	experiences, know-how transfer, training possibilities

Further steps

Based on the data gathered through the feasibility study, it will be possible to elaborate recommendations and a strategy of work. From experience, a special attention has to be paid to the following aspects:

1 - Architectural choices:
These should be made taking account of cultural references.

2 - Technical choices:
They must be adapted to the specific local conditions. The degree of complexity of the building principles, their flexibility, and their replicability must be taken into account.

3 - Demonstration:
Test buildings must be erected. These enable the acceptability of the proposed models to be verified, the technical and architectural choices to be refined, and the overall level of skills and knowledge, and therefore of the quality of built examples, to be improved upon.

4 - Professional training:
This should be provided at all levels in order to create teams capable of undertaking projects from design to building stage, as well as the maintenance of the buildings.

5 - Quality control:
Good supervision has to be put into place in order to ensure the quality of the constructions.

6 - Technical assistance
For a minimum period, keeping in regular contact with partners who are experienced and able to give technical help or advice is recommended.

7 - Commercialisation:
Promotional and commercial activities might be necessary in order to ensure the minimum quantity of work allowing the amortisation of your investments in the technology.

BUILDING OPTIONS AND ARCHITECTURAL / ENGINEERING DESIGN

Choosing between options

Each arch, vault and cupola has specific properties and technical and architectural capabilities. Therefore, it is important to have a good understanding of the various "families" of building systems and the architectural possibilities which follow on from these, in order to be able to make a relevant choice between options. Such choices, indeed, have a very great influence on the acceptance and the appropriation of the technology. Therefore, attention has to be taken in order to meet all the different facets of the needs and constraints of a construction.

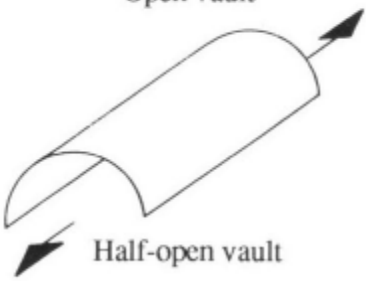
Building

The various forms of arches, vaults and cupolas are closely linked to one or more building methods. They are more or less inexpensive, depending on how much specialized equipment is needed and how difficult the construction work is. The issue of scaffolding is also an important factor and can determine the preferred dimensions, notably for the height of the arch, vault or cupola.

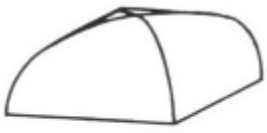
Spatial considerations

The curved forms generated by arches, vaults and cupolas define free variable heights which increase with the span and the rise.
Depending on requirements, one should first determine the curvature of the element and the height of its spring-point.
The ability to move between one space and another also makes it important to take account of the ability to open out between the interior and the exterior of a vault or of a cupola. One can distinguish between open, semi-open and closed types.

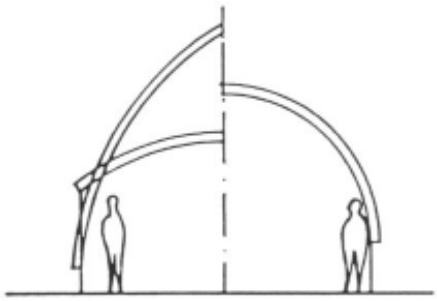
Open vault



Half-open vault

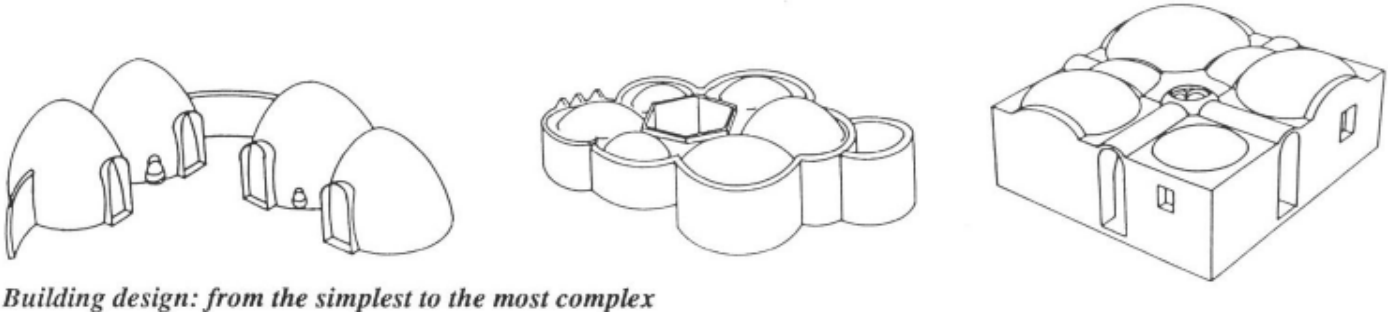


Closed vault



Building complexity

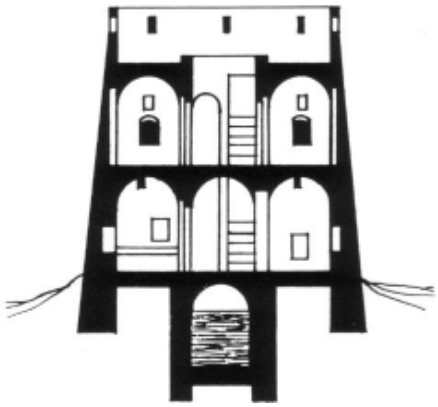
Building systems using arch, vault and cupola structures can range from the simplest to the most complex. The main distinction to be made is between modules which are independent from one another (whether connected or not) and sophisticated systems which respect very precise geometrical traces.
The sophisticated systems enable to get an optimum use of the material and perform very well from the point of view of costs. On the other hand, their replicability can be tricky as a high degree of precision at the laying out stage is required.
As a general rule, the more the shapes of the vaults or the cupolas are visible, the cheaper the building. Certain models permit a simple and inexpensive transition to flat or sloped roofs.



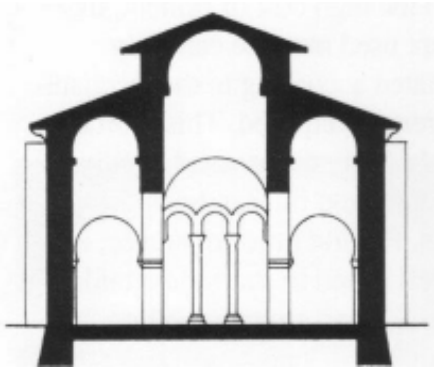
Building design: from the simplest to the most complex

Architectural appearance

Arches, vaults and cupolas offer a very great number of architectural possibilities with a more or less typical and attractive character. These depend on the materials and models used, the methods of utilisation, and finally the building techniques which are linked to them. The architectural aspect is one of the principle vectors of cultural and social acceptability of a technology.



Section of house in Sfax, Tunisia



Section of church, Valladolid, Spain

Designs for various shapes of building:
curved, flat or sloping roofs

Acoustics

The rounded shapes, especially of cupolas, can result in a significant degree of reverberation which is an asset or a disadvantage depending on the intended use of the space. Simple measures, such as corbelled elements or suspended cloth, can be used to reduce reverberation.

Stability of arches, vaults and cupolas

To ensure stability, the form should be as close as possible to the line of force. In the case of vaults, for evenly distributed loads, the best form resembles that of an inverted suspended chain (catenary). This applies both to flatter and to slender forms.
The corresponding ideal cross-section of a cupola is somewhat different and can only be worked out graphically or mathematically. Combining vaults and cupolas results in more complex issues of stability and allows much more flexibility in shape.

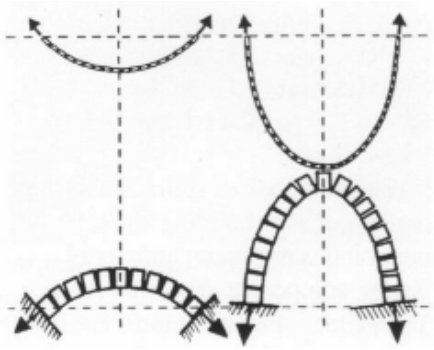
Stability of supports

Arches, vaults and cupolas are heavy roofing elements and they exert thrusts which increase with the degree of flatness, the span and the weight of the structure. These thrusts may be concentrated or dispersed. They have a tendency to push out the supporting bases (walls, piers and foundations) and must be taken into consideration. The most common solutions are: cancelling them out by juxtaposition, widening the wall, buttresses, and tie-beams or ring-beams.

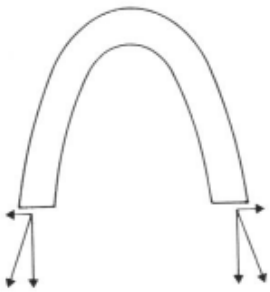
Project for a 2 classroom block, Senegal

Details and finishings

Details and finishings can influence the choice of structure. Attention must be paid to:
- the bonding pattern(s), particularly for visible masonry,
- channelling and removal of rainwater,
- window frames.



Forms of "inverted chain"



Segmental arches exert greater thrusts than slender arches

BUILDING MATERIALS

The building materials required for the masonry of arches, vaults and cupolas can be divided into two broad groups: solid components (adobe, stone, etc.) and binder components (mortar). The solid components ensure compressive strength. The binder components ensure that compressive forces are transmitted and the cohesion of the whole.
To avoid the risk of shrinkage during drying out after building work, preferably a minimum amount of binder component should be used.
The various solid and binder components are rarely incompatible but it is preferable to use components of similar strengths.

Solid components

Stone:
Stone is often of very irregular dimensions, which forces one to use very expensive preparation and implementation techniques. Soft, light stone offers interesting possibilities, as does layered stones, which can be standardized by simply chiselling them to the required shape.

Moulding an adobe block into the shape and size required

Adobe block:
Simply prepared by moulding plastic soil and leaving it to dry, the adobe block is always inexpensive. Its shape and size can be easily adapted to the various methods of construction, so that this material is the most widely used. However, its rather low mechanical performances require the construction of fairly massive structures.

Stabilized compressed earth block:
Being insensitive to water and having good mechanical strength, this material provides an alternative to the more costly fired brick. Most of the presses used to manufacture compressed earth blocks can be adapted to produce special blocks.

Plain moulded cement blocks:
Made from sand-cement mortar, these blocks have been used for very diverse buildings as many shapes and sizes of both simple elements, and also of special parts, can be prepared.

Fired solid brick:
This material is more expensive but generally performs well, which allows for either lighter buildings or larger dimensions. Special shapes and sizes can be obtained, depending on the means of production.

Fired hollow brick:
This enables special application techniques to be used, and very light buildings to be realized. Materials produced using craft pottery methods can be used in a similar way.

Binder components

Earth mortar:
This is used to bond adobe, fired brick or stone. Its good sticking properties enables one to build vaults and cupolas without shuttering.
Plastic earth mortar can be used to make hand-shaped cupolas.
To avoid shrinkage, straw or sand is added to soils with an excessive clay content.

Stabilized earth mortar:
Cement, lime, plaster or bitumen improve the characteristics of earth mortar. Such mortars are very suitable for binding compressed earth blocks or fired bricks.

Lime-sand mortar:
This displays average characteristics; its main advantage is that it stays malleable for quite a long time and sets very slowly. It can be improved by adding crushed brick or pozzolanas. Lime-based mortars are very frequently used in conjunction with fired brick and stone.

Cement-sand mortar:
Given the high cost of cement, the amount used must be carefully calculated according to the mechanical strength required. This mortar is suitable for bonding good quality fired earth and full sand-cement blocks. Having little adherence, it is not well suited to shutterless building methods, apart from corbelling.
Medium-span vaults have been made directly using a sand-cement mortar.
Small size elements can be prefabricated.

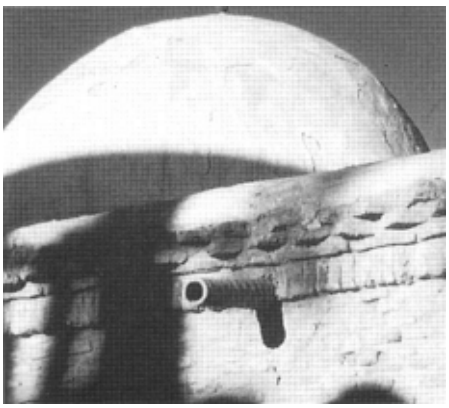
Gypsum mortar:
This sets very quickly, which enables adhesive application techniques to be used.
Small span vaults can be made or even prefabricated directly using this mortar.
The stability of water-soluble gypsum can be improved by combining it with lime.

Surface protection

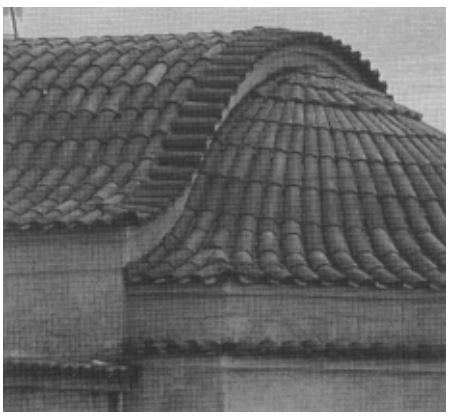
To avoid infiltrations and therefore risks of detoriation,vaults and cupolas must be protected from rainwater, which must be channelled away from the building, using water-spouts or downpipes.

Renders:
An earth render is the least expensive, but requires periodical maintenance whose frequency which depends on the nature and the quantity of rainfall. .
A sand-cement mortar is too rigid and will always crack, which allows water infiltration to take place. It should not be used without a complementary membrane.
Lime-sand and gypsum-lime-sand renders are better suited because of their greater pliability, but a certain amount of maintenance might still needed.

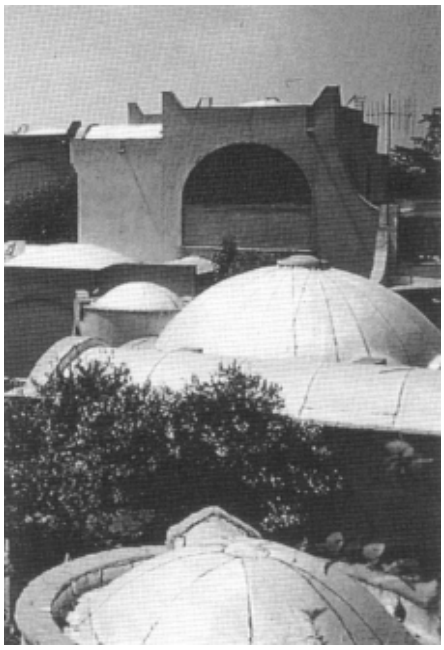
Earth plaster is efficient but often requires maintenance



Ensuring water run-off through a water-spout



Tiled roof cover



Multi-layer water-proofing

Roof coverings:
Certain forms of vaults and cupolas can be protected by roof coverings made of thatch, flat stones or even tiles. Although rarely used in recent projects, these solutions can be very efficient while remaining cheap.

Membranes:
Membranes consisting of a single or multi-layer bitumen-based material, of waterproof paint or of metal leaves are efficient, but often too expensive.

Flat and sloping roofs:
A great many solutions are possible here, but the choice of the shape of the vault will be crucial to the simplicity of implementation and to economic considerations. The simplest solution is to use a compacted earth and gravel infill, on which the water-proof layer is placed, but solutions including very light wooden structures are also possible.

EXECUTION

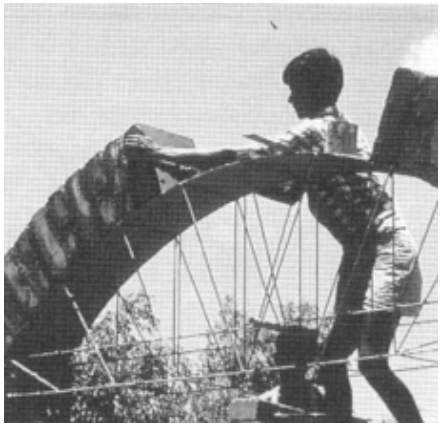
Building arches

With formwork:

For building an arch, a formwork of the same shape of its intrados needs to be used. This can be made of wood or metal and should be used in conjunction with a system allowing its easy removal.

For most arch forms, the formwork can be removed immediately after construction. The formwork can therefore be reused straightaway. This means that if there are a great many identical arches to be built, clearly it makes sense to prepare a precise and robust formwork to ensure that it can be reused and that the work will be of high standard and carried out quickly and economically. Building up bricks or blocks with dry joints and shaping the curve with a layer of mortar is a very economical way of making a formwork.

Wooden formwork

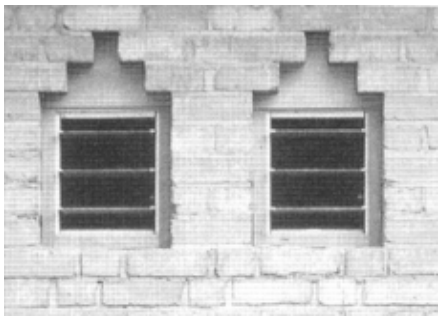


Metal formwork

Brick formwork

Without formwork:

Corbelled arches are built using courses which each jut out further than the previous one. Cut out arches, and arches shaped with wooden reinforcement, are also built without formwork.



Corbelled arches

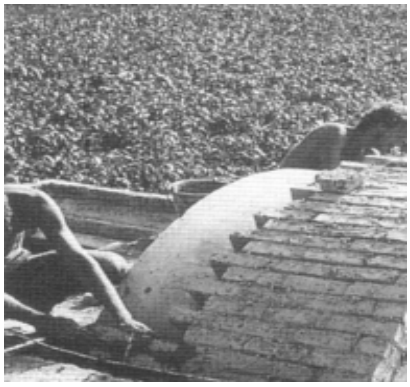
Building vaults

Vaults can be built in a similar way to arches.

With formwork:

Building can be done on a full formwork set up in place. This is mainly used for floors over basements.

It is possible to use an integrated formwork. Being very heavy, this has to be assembled and dismantled in place. This technique is economical only if the vaults - and therefore the formwork - are light.

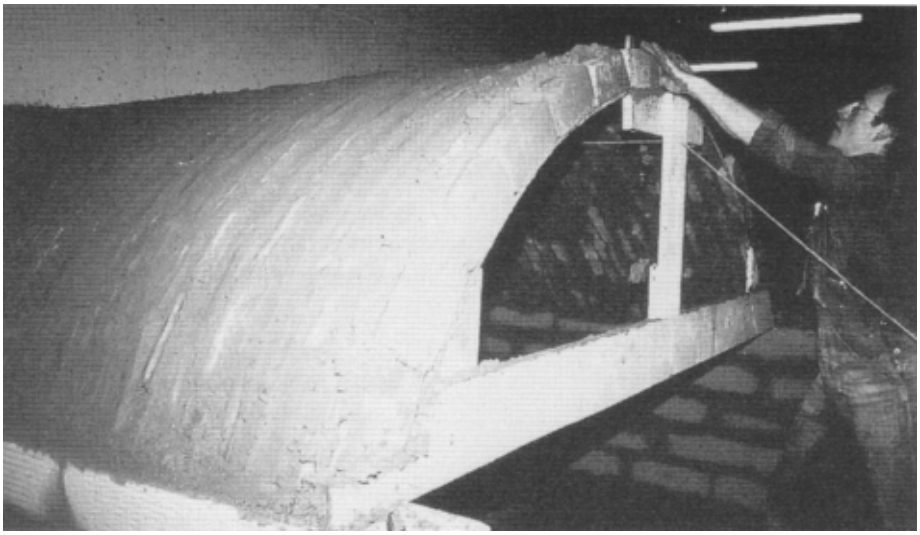


Sliding formwork

TOOLS AND SKILLS

Sliding formwork:
Building takes place in stages, with the formwork being repositioned as often as necessary. This is one of the most interesting methods, but applies only to barrel vaults.

Without formwork:
Corbel vaults can be built only using small spans.
Building in so-called "slices", without formwork, is the most economical method. This exploits the properties of certain mortars which enable the bricks to be laid face on layers leaning at a steep angle to the vertical. To improve adhesion, small and fairly thin elements of regular dimensions should be used.
Using this principle, and by varying the shape and the size of the courses, one can build barrel, groined, dominical, trough, squinch and boat vaults.
Traditionally, all these vaults are built "by eye", but light tools can be used to guide the masons so that they build the required shape correctly.



Building a barrel vault in "slices"

Squinch vault

Building a cupola using inclined ring-courses

Building cupolas

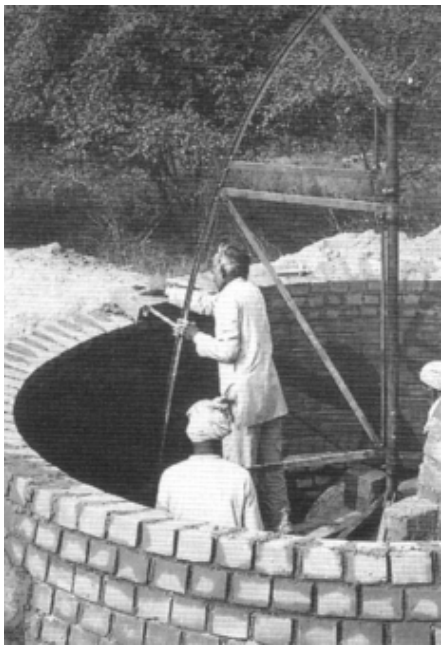
Building techniques without formwork are always prefered as a formwork would be too complicated to manufacture.

Corbelling:
This enables large areas to be covered, but results in conical forms which are very high relative to the span.

Increasingly inclined rings:
Horizontal rings which gradually decrease in diameter can be used to create all types of cupolas. This method uses the same brick-laying technique as for vaults built in "slices".
Simple rotating guides which describe the form in the air can be used to obtain correct, regular forms.

Hand shaping:
Using a straw-reinforced earth mortar, it is possible to build fairly large sized cupolas. These are built up in successive layers.

PROFESSIONAL TRAINING



The need for training

Current training courses teach very little about the particularities of arches, vaults and cupolas and about techniques to build them. Specific professional training has to be provided for all concerned, from designer to builder.

"Design know-how"

Designing buildings with arches, vaults and cupolas calls for specific engineering knowledge, principally including spatial geometry and principles of stability. The various technical solutions or architectural variants also need to be known in order to enable the technology to be adapted, to be used creatively and to evolve.

"Building know-how"

Although the main masonry principles apply, specific building techniques must also be used. Even though these call for some tricks of the trade and specific tools to be used, these techniques are quite simple, and they can be mastered very quickly.

Structural principles should also be well understood, so that adaptation to special or new situations can occur.

Although formal training will always remain the most efficient, on-the-job training on sites supervised by qualified staff is a good way of acquiring practical skills at an affordable cost.

After theoretical training, learning on site is vital to acquire real skills

PROJECT MANAGEMENT

The market

The construction market is in general very conservative and it is not always easy to introduce new ideas into well-established contexts. Promotional activities might have to be undertaken to penetrate the market.

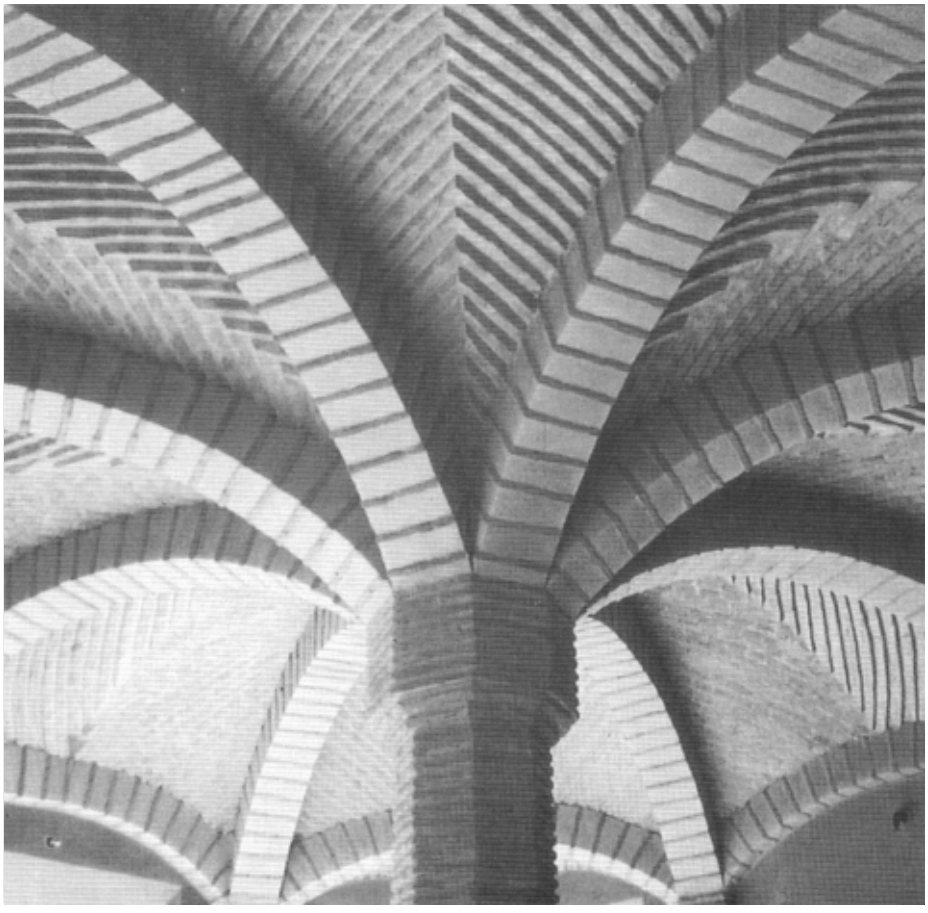
Promoting and informing

Demonstration projects are necessary. This means that opportunities to construct "show" buildings must be found. High standard buildings are of interest, because they are appreciated by the general public and can be designed and built using simple principles, which can then be exploited for more economical housing.

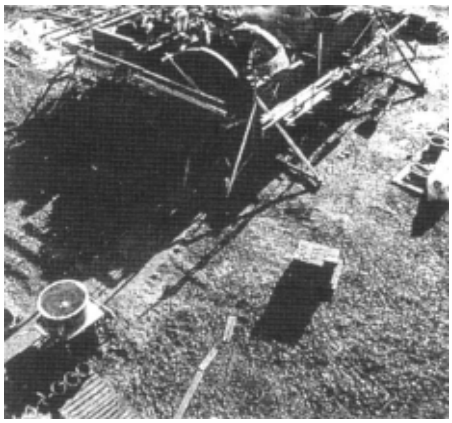
The public needs to be made aware of the possibilities which are offered by buildings with arches, vaults and cupolas. Awareness-raising activities, showing their full potential, can be considered around the first buildings.
Dissemination activities made by trained professionals is very efficient and effective.

Ensuring quality

Top quality work is important to gain people's confidence. Particular attention should be paid to the control of site work: execution, planing, raw and building materials, and maintenance of equipment.



Quality of finishings, a major asset



Good organization enables work to be carried out quickly; site of a house built in 24 hours

Site management

Building with arches, vaults and cupolas does not pose any particular management problems.
However, two points can be of importance: special equipment and building seasons.

Special equipment

Special equipment (e.g. arch formwork) is not found in the normal building materials trade. Manufacturing it to avoid building delays will have to be planned in advance.
To ensure a good amortization of the equipment, planning at the design stage can allow for using equipment several times in the same building, or in different buildings, by repeating shapes and using standard dimensions.

Building seasons

Even if the materials used are water-resistant, the building planning should preferably allow for the water-proofing to be done before rainfall periods, which can then be devoted to inner finishing works.

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Office building of the Center of Energy Studies at the Indian Institute of Technology, New Delhi, India

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Unless otherwise stated, all photographs are by the author. Illustrations: Patrick Idelman.
From left to right and up to down.
Front cover: Construction of a 9 m diameter "star" cupola in compressed earth blocks, Calvi, Corsica, France.

p.2 The town of Thera, on the island of Santorin in the Cyclades, Greece.
p.3 Elevation of the "Andrioli house", Fayoum, Egypt, 1984, in Hassan Fathy, Architectural Monographs, see bibliography. p.4 House built in adobe bricks near Aswan, Egypt; photo: P. Doat.
p.5 Dar al Islam community building, Abiquiu, New Mexico, USA; a project of architect Hassan Fathy; photo: P. Odul.
Postage stamp issued in Niger in 1992 on the subject of "Woodless Construction".
p.6 Experimental building at the Rural Housing Research Centre, Dakar, Senegal.
Information and reception centre of Auroville , India; architects: S. Ayer-Guigan and S. Maini; photo: S. Maini.
p.7 Interior of St. Bartholomew church, Zaria, Nigeria.
House built using principles suggested by the "Woodless construction" project, Niger, designed and built by P. Tunley of Development Workshop; photo: A. Douline.
p.8 Arcatures of provisional mausoleum for Indira Gandhi, India; architects: S. Patara; photo: H. Guillaud.
Rural house in the Dades valley, Morocco.
Interior of reception building, "Village au bout du monde", near Mâcon, France.
Interior of 24-hour house, Grenoble, France.
p.11 Rural housing on the shores of Lake Titicaca, Bolivia; photo: Th. David.
Adobe vaulting cells on palm trunks, Marrakesh, Morocco; photo: P. Doat.
Administrator's accommodation, training centre for rural supervisors, designed and built by ADAUA, Kamboincé, Burkina Faso.
Barn, Causse Méjean, France; photo: G. Beraldin.
Farm in the Qeuyras region, France.
p.12 Village Development Centre built using principles suggested by the "Woodless construction" project, Niger, designed and built by P. Tunley of Development Workshop; photo: A. Douline.
p.13 Private house, Marrakesh, Morocco, designed and built by architect E. Mouyal.
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Maintaining the earth render of the roof of the Zaria mosque of the Jos museum, Nigeria.
Dome and water-spout of house in the town of Tozeur, Tunisia.
Tiled roof cover of small church on the island of Santorin, Greece.
p.20 Wooden formwork, Ivory Coast; photo: Ph. Romagnolo.
Corbelled arches, Passamainti, Mayotte.
Metal formwork, Auroville, India; photo: S. Maini.
Brick formwork, building exercise, School of Architecture, Grenoble, France.
Construction with a sliding formwork, CSTB, Grenoble, France.
p.21 Building a barrel vault in "slices" using a light-weight guide, building exercise, Grenoble School of Architecture, France.
Building a squinch vault, Tabas region, Iran; photo: Abedini Rad.
Building a cupola using increasingly inclined ring-courses, near Mâcon, France.
p.22 Building a cupola using a guide, Office building, IIT, architect: G. Minke, energy concept: N.K. Bansal, India; photo: G. Minke.
Builders' training on the site of the 24-hour house, built by CRATerre-EAG with AFPA, (the Adult Professional Training Association), Grenoble, France.
Idem.
p.23 Site of the 24-hour house.
Private house, Marrakesh, Morocco, designed and built by architect E. Mouyal.
p.24 Office building financed by GTZ/GATE; architect: G. Minke, GhK, Germany; energy concept: N.K. Bansal, IIT, India; photo: G. Minke.

Back cover: Stages in the construction of the 24-hour house, CRATerre-EAG, Illustration: J. Esteve.

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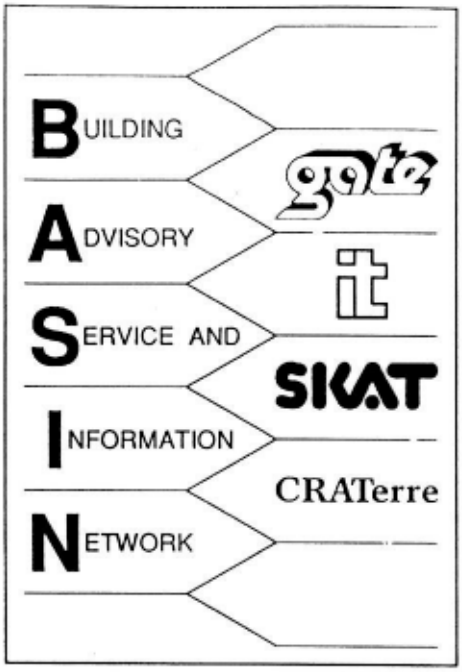

BASIN

Building materials and construction technologies that are appropriate for developing countries, particularly in the low-income sector, are being developed, applied and documented in many parts of the world. This is an important prerequisite for providing safe, decent and affordable buildings for an ever-growing population.

But such new developments can do little to improve the building situation, as long as the information does not reach potential builders. The types and sources of information on standard and innovative building technologies are numerous and very diverse, making access to them difficult.

Thus, in order to remedy this drawback, GATE, ITDG, SKAT and CRATerre are cooperating in the Building Advisory Service and Information Network, which covers four principal subject areas and coordinates the documentation, evaluation and dissemination of information.

All four groups have a coordinated database from which information is available on Documents, Technologies, Equipment, Institutions, Consultants as well as on Projects and Programs. In addition, printed material or individual advice on certain special subjects is provided on request. Research projects, training programs and other field work can be implemented in cooperation with local organizations, if a distinct need can be identified and the circumstances permit.

BASIN is a service available to all institutions and individuals concerned with housing, building and planning in developing countries, but can only function efficiently if there is a regular feedback. Therefore, any publications, information, personal experiences, etc. that can be made available to BASIN are always welcome and will help BASIN to help others.

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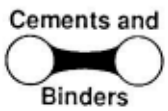
The Information and Advisory Service on Appropriate Technologies (ISAT), a project of GATE, has accumulated specific know-how in the wall building sector through its own research and development programmes, studies and publications. Own capacities and a team of experts are available for advice on wall construction and wall building materials.



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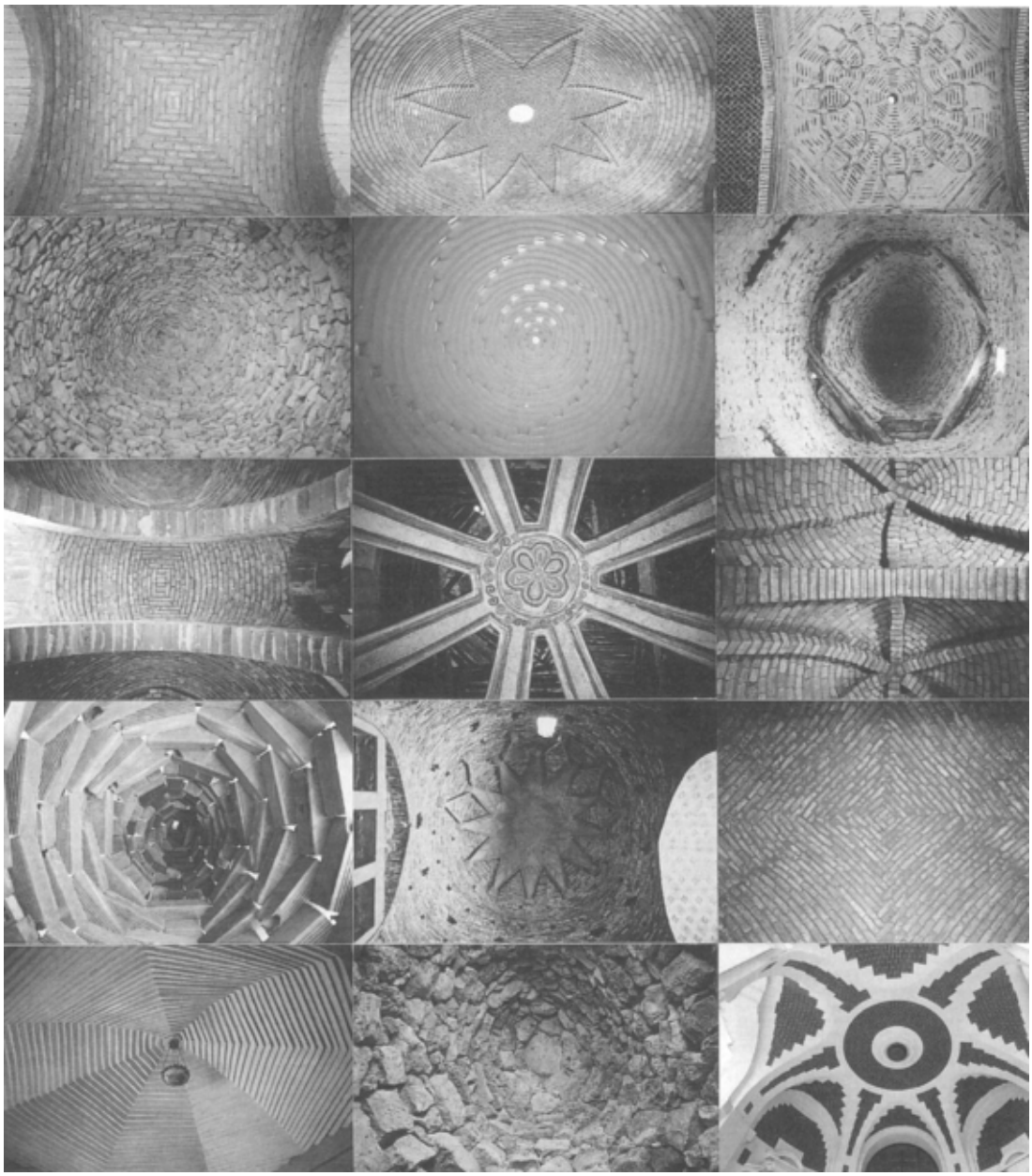
The three main programs of development are: i. Industrialization; ii. Economic Housing; iii. Preservation.
The competence of CRATerre covers every aspect of the different earth construction technologies at all levels.



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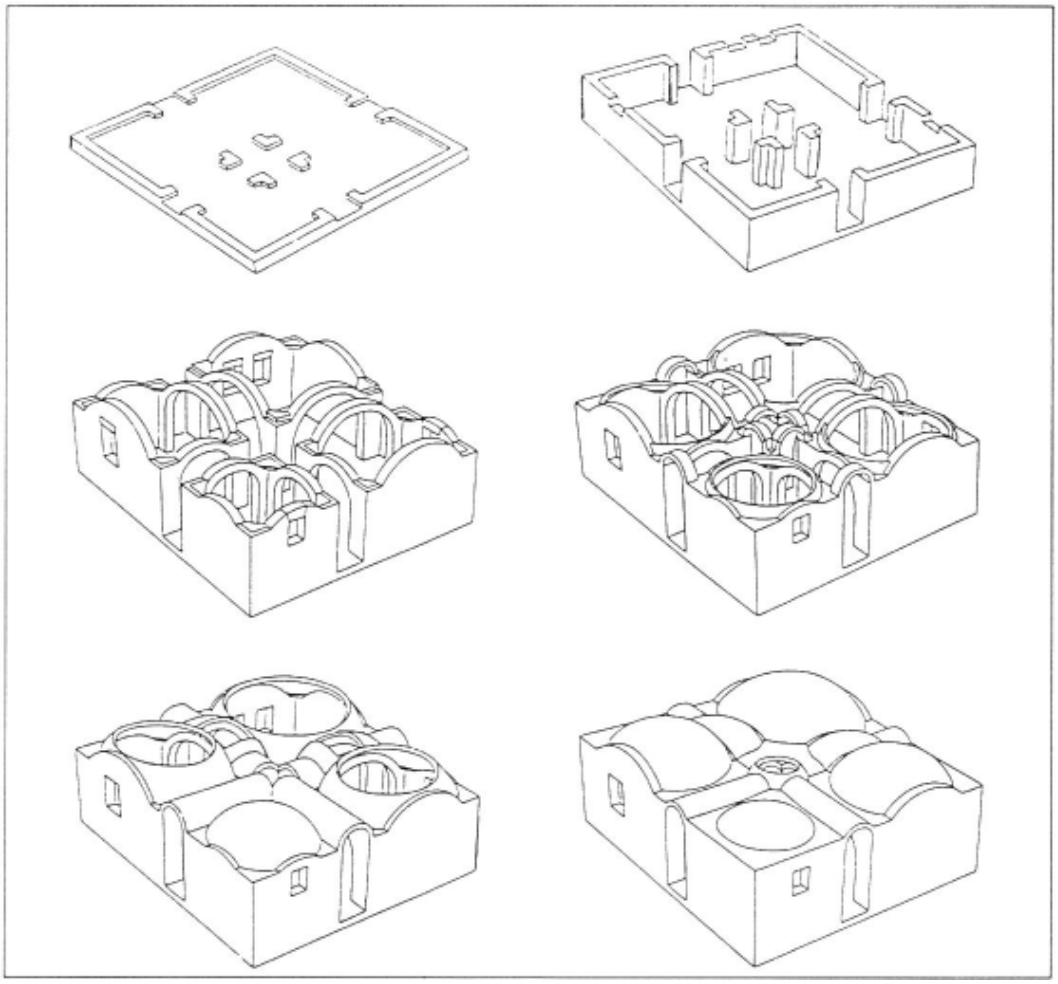
Don’t hesitate to contact us

BASIN



WHO MAY BE INTERESTED IN THIS BOOKLET?
Decision-makers, architects, engineers, project managers, building entrepreneurs, and all who wish to know more about building with arches, vaults and cupolas.

WHAT YOU CAN FIND IN THIS BOOKLET?
Basic information about building with arches, vaults and cupolas.
The advantages and limitations of arches, vaults and cupolas.
Recommendations, bibliographic references and addresses for getting more information.

WHAT YOU WILL NOT FIND IN THIS BOOKLET?
Detailed technical information.
Information relating to local conditions.