ROOFS

PART 1

YONA FRIEDMAN

HUMAN SETTLEMENTS
AND SOCIO-CULTURAL
ENVIRONMENT

UNESCO

Habitat Scroll of Honour 1992 (UNCHS)
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE

UNDER THE AUSPICES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

33, BO GARIBALDI, 75015 PARIS (33i) 783 20 24

ROOFS
MADE WITH VEGETAL MATERIALS
The manuals in this collection have been conceived in order to make simple roof-building techniques available to people who have little education and almost no resources. Thus, the techniques presented here are appropriate for self-help building and make use of inexpensive local materials.

It is for these people and for those who are called upon to assist them in their building efforts, that each technique has been presented in sketch-like, non-technical drawings, with short texts. The drawings can be copied easily, even by those without drawing skills.

Roofs are the main subject of these manuals, since roofs appear to be the most complex part of simple shelter. It is less difficult and requires less know-how to build walls and partitions than to build a roof. Roofs are, in fact, more exposed to all kinds of influences and stress than other parts of a shelter. This is the reason why these manuals do not consider foundations, walls, etc., beyond their functions as a support system for the stability of the roof.

The manuals were primarily prepared for the lowest income people in India, a subcontinent with varied climatic conditions, diversified local resources and a wide range of traditional skills. It was the intention of the authors to describe techniques unknown in certain regions without putting, however, too much emphasis on those techniques which are generally known and widely used. The target groups appear to be more attracted and concerned by proposals concerning innovative techniques.

The material in this collection is presented in five major sections:
1. Generalities
2. Techniques using materials of vegetal origin
3. Techniques using materials of mineral origin
4. Principles of simple engineering
5. Security

An Annex indicates the list of materials relevant to each region of the subcontinent.
A. THE COMPLEX PROBLEM OF HOUSING

"Housing" is more than "shelter" and less than "habitat". Indeed, "shelter" simply constitutes a means of protecting against outside aggression, natural or human. "Housing" represents more than just protection, but provides a framework for living, for a wide set of social as well as self-supporting activities. Finally, "habitat" is again different and involves much more than just "housing": it includes all elements of the environment needed for human existence.

Housing is part of habitat, shelter is part of housing.

Before discussing the problems involved in this project, it seems necessary to define these terms. The project presented here deals with a set of technical elements of housing, but, in order to better understand the choice of solutions, an overview of the "problématique" was necessary.

Housing problems are not restricted to the poor. The solutions we want to put forward concern all societies. But since we have to set priorities, emphasis was put on techniques accessible for the poor members of society.

The general problems of housing can be classified into three principal domains: that of social, environmental and technical criteria.

B. SOCIAL PROBLEMS

First of all, housing projects should facilitate autonomy and survival. For example, a house depends on outside supplies (water, energy, food, etc.) but it should be conceived to remain independent even if those supplies are no longer available. Air, water, heating, etc. can be controlled by sophisticated devices, but it is essential that, when such devices fail, supply and control should be available through unsophisticated means. Cisterns, windows, etc. are among these means.

Another social problem concerns the financial aspects of building of houses. This can either be done in cash or in kind (meaning building by the user himself).

The location of the house appears to represent yet another social aspect, and an important one, as it signifies "status", can facilitate economic integration and guarantee security. The solution to this problem and an acceptable distribution of sites is a difficult matter to be dealt with in settlements. This aspect will, however, not be covered in this paper.

C. ENVIRONMENTAL PROBLEMS

A man-made artifact (e.g. a house) on the ground can be considered as representing a major impact on the environment. That impact is not actually restricted to the area covered by the roof, but includes all open spaces which are directly or indirectly part of the house: courtyard, lanes, working areas, etc.

In a broader sense, the impact on the ground includes all areas, even distant ones which serve that particular house (including community services). These include shopping areas, roads, water distribution and collecting systems and, consequently, all areas which no longer belong to the natural environment.

Thus larger houses can have less impact than smaller ones, if they are more autonomous. Therefore the impact on the ground largely relates to lifestyle.

Building materials for housing also have an impact on the environment. The provision of building materials often implies large gaps in natural environment (e.g. quarries deforestation). Generally speaking, the gaps resulting from the exploitation of vegetative raw materials can be more easily filled, such as a clearing in a
wood, whereas a quarry remains a hole for ever. Consequently self-renewing materials are preferable, especially those which are renewable in the short-term (i.e. bamboo). The material needed for a bamboo building can be grown on about a sixth of the area needed for a building.

D. TECHNICAL PROBLEMS

All aspects described above converge in fact on one technical problem. Thus, economizing on building materials also means positively reacting to both financial and environmental needs; the stability of a building is linked with its autonomy. The possibilities for self-help construction and consequently self-help maintenance depend largely on the techniques employed.

In conclusion, the project proposed offers technical solutions to the whole "problematics" of the above mentioned social and environmental aspects. Although the project was conceived to be carried out by disfavored people, all considerations and the corresponding techniques can be applied to the middle class, and even to the rich. In other words, if these techniques are suitable for low-income groups, they should be made available to all income groups. Indeed, bamboo domes could be used as a technique for both houses and palaces.

The technical solutions presented in this project concern roofs alone (with a few general topics of simple engineering added). Roofs are the most important and technically speaking, the most complex elements of buildings. They are an essential part of shelter.

If "habitat" means "food plus roof", the manuals presented cover half the habitat problem.

E. THE WAY THE TOPICS WERE SELECTED

There are many techniques used in the building of a roof; in the selection that follows, the considerations exposed above were used as guidelines.

The first principle is related to the choice of the building material. The concept of "local material" is too vast: they include both natural and artificial materials. Plastics, cardboard or industrial fallout are, in a way, also local materials. Natural materials can be renewable or not. Some of them can be grown easily on a small area, others grow slowly and immobilize large plots for a long period.

In this paper, priority has been given to materials of natural origin. We preferred bamboo, a fast growing plant which occupies less surface area than the building for which it is used. Wood was considered only when absolutely necessary (e.g. pillars), or in cases where scrap wood was used.

Reeds and grass bundles which can be used for interesting roof structures are also mentioned.

Techniques using mineral resources were restricted to sunbaked bricks. The techniques used to produce them are among the least harmful to the environment.

Emphasis was put on roof structures: structures of a reasonable span (4-8 meters), supporting a light-weight roof skin (except in the case of brick domes). The roof skin is composed of sophisticated materials with locally available materials. Bamboo mats, cardboard, etc. are materials used in most shanty towns (and also in many palaces). These materials, combined with waterproof and heat reflecting materials (i.e. aluminium or plastic foil) can guarantee a decent shelter.
Another important criterion is the adaptability of the chosen techniques to self-help building. Thus, the selected techniques should be easy to handle for laymen with simple tools. They involve very little cash investment, and are time-saving. In a few test constructions, it was shown that people having no professional experience in that field, can do the job.

Some of the elements used in building the roofs (mats, rings, bundles) constitute a sort of “village representation”, performed by ordinary craftsmen. The same is true for sunbaked bricks or other ceramic components (jars, etc). Obviously all these techniques could be used for industrial production if appropriate finance is available.

The characteristics of the project are simple “cartoon type” manuals conceived for use by a public of potential self-help builders and local craftsmen. Another criterion for the selection of techniques was their adaptability for easy communication. The techniques chosen are easily explained and understood by the target public, whether literate or not. And all this with a few cartoons which look very simple and rough, but which are, in fact, very sophisticated.
Making Your House

- What Can You Build With and How? p. 19
- Choosing Materials p. 27
- Flat Roofs p. 35
- Space Frames p. 45
- Bamboo Domes with Suspended Mat Cover p. 51

Lattice Domes

- Bulb-Shaped Domes p. 75
- Rings Into Roofs p. 81
- Structures Made with Ring-Balls p. 89
- Roofs Made with Rings (Space · Chains) p. 101

Ropes and Rods

- Freely Shapeable Roofs p. 121
- Dome Structures with Flexible Materials p. 127
- Building with Grass p. 133

Contents
You don't have a house.

If you don't have a roof.

A house begins with a roof.

But some parts of the house don't need to have a roof.

Courtyards, terraces.

Sometimes you prefer to be at home under a roof.

Sometimes you are at home having only the sky over your head.

What you need to build to have a house

Is a roof.

A roof protects you from the sun, from the rain:

It is like an umbrella.

A roof is a sheet

Over your head;

The same sheet is not a roof

Unless you lift it over your head.
The roof is held over your head

(for example) by a few stilts.

The stilts are not a house.

A roof on stilts can be a house.

If you open a hole in the roof on the stilts,

You get a courtyard.

Sometimes you don't want people to see you when you are at home.

Then you use screens, to hide those parts of your home you don't want people to see.

These screens protect also... your belongings from theft.

At other times, or in some other parts of your home, you like to be seen from outside.

There you don't use screens.

Parts of your home hidden by screens (having or not having a roof)

Are enclosures.
IF YOU HAVE ENCLOSURES

YOU HAVE TO LEAVE AN ENTRANCE,
AND OPENINGS
FOR LIGHT AND AIR.

YOU CAN MAKE WINDOWS.

BUT IT IS SIMPLER AND CHEAPER
TO LEAVE A GAP
BETWEEN THE ROOF ON THE STILTS
AND THE UPPER EDGE OF THE SCREENS.

IF YOU NEED MATERIAL HELP
TO BUILD YOUR HOUSE

AND YOU HAVE
GROUND TO BUILD ON,
THE STILTS AND THE ROOF
ARE THE MOST IMPORTANT,
THE SCREENS YOU CAN DO
YOURSELF.
You can construct the walls in a way you already know. In mud bricks or modelled mud walls, or with woven branches and mats.

These techniques are good ones because you yourself can find the necessary materials on the spot where you live, and you yourself know how to repair such walls to keep them in a good state without needing other people's help.

The government's role is, first of all, to protect the user of the land: those who squat somewhere have to be assured to have the right to stay there.

It is the government who decides about networks (roads, water mains, sewers etc) which are supplied the communities but the inhabitants themselves have to decide about networks within the community.

Distribution of expensive building materials (for example, for the roof) is the government's task as well.
THE MOST IMPORTANT THING REQUIRED FROM THE AUTHORITIES

IS THE RIGHT TO USE UNUSED LAND AND MATERIAL FOR THE ROOF.

YOUR GOVERNMENT

CAN HELP YOU WITH BOTH.

IF YOU GET HELP IN THESE TWO MATTERS

YOU WILL BE ABLE TO MAKE YOUR OWN HOUSE.

IF YOU OBTAIN SUCH LAND, FOR YOU AND YOUR FRIENDS,

STILTS ON THE LAND,

AND A ROOF IN COMMON ON THE STILTS,

YOU CAN MAKE OPENINGS IN THE ROOF

CREATING THUS COURTYARDS GIVING LIGHT AND AIR AND ACCESS TO ALL THE HOMES SHARING THE SAME LAND AND ROOF.
When making enclosures under the "roof in common" and around the courtyards,
you start to make your houses. Each of you can plan them as he wants.

Some enclosures can be square, some others round.

Some enclosures wide open to the street, some others dark and private.

Some enclosures large, some others small.

And so on.

You might like some enclosures to be round,

And some others square.

You can build them two ways.

If your screens (walls) are separated from the stilts supporting the roof,

Then you can change the shade and place of your screens, and move them (like you can do with a chair under a table) without the roof falling in.

Houses are as different as people.

But how to make the plan of your house?
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE
UNDER THE AUSPICES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

WHAT CAN YOU BUILD WITH
AND HOW?
Walls can start directly from the ground.

But if you want to have them more solid,

It is better to build them on foundations.

Foundations are made of materials which do not become soft when wet,

which do not rot when buried in the soil,

and which are solid enough to bear the weight of the wall.

For making solid foundations you first dig a ditch deep enough to reach those layers of the soil which don't yield and broad enough to distribute the weight of the wall for the soil.

You put bricks or stones into this ditch if your house will have heavy walls.

And you should make the lowest layers of the wall of the same materials.

So even high water does not do much harm to your walls.

Foundations are the roots of the house.

And like roots do, they are deeper and larger than are the walls themselves.
Walls keep heat, cold and water out of the house and can be useful to hide things you want to keep hidden.

Walls can also bear the roof.

Walls which bear the roof must be solid and often heavy.

Made out of dry earth, sun-dried earthen bricks, or bricks burnt in fire or stones.

Whichever are accessible for you.

In order to build with mud you have to have earth which gets hard when dry.

When you use such earth which should be wet enough to be mud, but not too liquid.

You have to mix it with chopped straw, cow dung, small pebbles, stones or gravel.

All materials which make dry mud more solid.

Occasionally you can mix this mud with some sand.

Most people living in a place know how good their earth is for building.
When building with bricks (earthquake ones, sun-dried or burnt)

You have to be very careful when building a brick wall.

You lay a row of bricks putting some wet mud (mortar) between any two bricks.

So you put a brick, mortar, another brick, more mortar, and so on.

When the first row of bricks is laid out, you should put mortar on the top of each brick.

Joints of a row should be shifted in relation to the joints of rows above and below it.

And watch that there is never a join between two bricks of one row directly above a joint of the row beneath.

Before placing a brick of the next layer on it.

If you do it well your wall will be more solid.
Once the wall is built, it has to be protected against humidity.

You can do this with plaster, applied to both the exterior and interior surface of the wall.

But, plaster is often not protective enough for mud walls.

Strong splashing rain destroys mud walls, washing away mud plaster and mud wall.

Better protection can be assured by fastening a straw mat on the outer surface of the wall.

The mat lets most of the water trickle down and it sheeters the mud wall from the rain beat.

You will find that a wall which is built in a straight line is less solid than a curved wall.

Or one built on a broken line:

A straight wall standing alone can not lean on itself, which a curved wall can do.

This a straight wall collapses more easily.
ROOFS CAN BE BUILT IN MANY WAYS

BUT THEY HAVE ALWAYS ONE THING IN COMMON:

THERE IS A "STRUCTURE" WHICH BEARS A WATER-TIGHT LAYER;
AND THERE IS THE WATER-TIGHT LAYER ITSELF.

IN MANY CASES THE TWO CAN BE THE SAME.

THE BEARING "STRUCTURE" CAN BE:

SIMPLE TIMBER GIRDER.

DOME OR VAULT "STRUCTURE" IN LIGHT MATERIALS, LIKE BAMBOO, GRASS BUNDLES, ETC.

IT CAN BE BUILT IN MASONRY ARCHES AS WELL.

OUT OF BURNT BRICKS OR STONES.

SOMETIMES THE FORM OF THE HOUSE CAN BE SO THAT WALLS AND ROOFS ARE THE SAME.
CHOOSING MATERIALS
THERE ARE MANY MATERIALS WITH WHICH ONE CAN BUILD HIS HOUSE, WALLS, AND ROOF FOR HIS FAMILY.

SOME OF THESE MATERIALS ARE LESS EXPENSIVE THAN OTHERS:

THOSE WHICH CAN BE GROWN ANYWHERE (LIKE BAMBOO)

OR WHICH NATURALLY GROW IN ABUNDANCE IN CERTAIN REGIONS (LIKE REEDS OR TREES WITH STRONG BRANCHES).
OTHER MATERIALS WHICH ARE INEXPENSIVE

CAN BE FOUND IN ABUNDANCE NEAR THE PLACE WHERE THE HOUSE WILL BE BUILT:

SUCH ARE: MUD FOR SUN-DRIED BRICKS

OR, IN SOME REGIONS, STONE.

BUILDING WITH SUCH MATERIALS MAKE THE HOUSE INEXPENSIVE

IF ONE CAN DO THE BUILDING JOB HIMSELF.

THAT KIND OF HOUSE CAN STAND FOR A LONG TIME

IF IT IS CAREFULLY MENDED EVERY YEAR.
Choosing materials to build is not only a question of cost.

It is important to examine how long that material will last.

How easy is it to build with it?

And how appropriate it can be to protect you against weather, against animals, and against ill-willed people.

But, protection against climate is not dependent upon the material alone:

The way it is used might be even more decisive.

It is important to know also what to expect from that building.
Vegetal materials, for example, (bamboo, reeds or branches) are very good roof supports, and in many cases, can be used as roof cover.

(Made of mats, straw or leaves).

Vaults and domes built with stones or kiln burned bricks are both good as support and as roof cover.

It is a different case with mud bricks, vaults or domes.

Which need to be protected from moisture, otherwise they collapse.

It is important to know how to choose materials and technique for the supporting structure and for the roof cover, appropriate to climates and to the abundance of inexpensive materials.
AN IMPORTANT POINT OF VIEW WITH BUILDING MATERIALS CONCERNS THEIR LIFETIME.

MOST MATERIALS KEEP ONLY FOR A LIMITED TIME:

REEDS AND BAMBOO DECAY IN ABOUT 10 YEARS, SOMewhat LONGER UNDER CERTAIN CLIMATES.

WOOD CAN KEEP EVEN UP TO 100 YEARS (IT DEPEND ON WHAT KIND OF WOOD).

CASUEENA WOOD, FOR EXAMPLE, KEEPS FOR A SHORTER TIME THAN BAMBOO.

VEGETAL MATERIALS ARE SUBJECT TO PESTS, PARTICULARLY TO TERMITES.

IT IS DIFFICULT AND EXPENSIVE TO PROTECT THESE MATERIALS AGAINST TERMITES.

IN TERMITE-SUITEN REGIONS TO BUILD WITH BRICKS OR STONES MIGHT BE MORE REASONABLE THAN TO BUILD WITH MATERIALS OF VEGETAL ORIGIN.
In regions where earthquakes are frequent, botanical materials, for structure, grant more security, provided they are used in the proper way.

Such materials can be advantageous in places where tides are common.

Besides using local materials, materials of industrial origin can be the better for certain tasks:

Such, as making the roof waterproof with plastic foils, or both waterproof and protected heat with aluminium foils. Both materials are not very expensive when their efficiency is taken in account.
FLAT ROOFS
In places where there is little rain, flat roofs are easy to build.

And where rain is not frequent, watertight roofs is not the main priority.

In such places, flat roofs can be appropriate.

They use up only little material (particularly if those materials used for the roof are light).

But even if they are built in semi-arid regions, they should be resistant to water.
The essential part of flat roofs is the beams.

Beams can be made of various materials:

- Wood
- Bamboo
- Metal rods
- Even bundles of reed can be used for beams.

The simplest arrangement of beams consists in spanning the distance between two opposite walls.

Obviously, if you have the choice you take the smaller span.
Using beams in this way
they sometimes have to be long
(as the walls can be far apart).

Then they have to be
strong as well,

Thus quite thick and high,
and so rather expensive.

Note: if the span doubles,
for example,

the beam needs to be
twice as high.

If the pieces of wood, or bamboo
are not long enough,
or strong enough,
you can make
other patterns of beams
which might be less expensive.
You can, for example, pose those shorter pieces in diagonals, cutting off the corners.

Thus 4 pieces of wood will form a smaller square than was the original room.

You can continue thus from small square to smaller square.

As a result you get a grid of beams, with smaller pieces of wood.
Another solution to the same problem consists of making a beam-net on the ground. Once the net is finished, you have to lift it into its place and fasten it onto the walls. Such a net is too complicated to be built directly in its final place.

Beside that, you can draw the pattern on the ground, which simplifies things. You should start by tying together a pieces of wood (using for this a very solid rope). So that they should form a small square in the center. And that each piece of wood should stick out of the square only on one side.
That "square with stems" will be the center of the net.

Tie now 4 other pieces of wood to each stem perpendicular to the stem.

And again 4 other pieces to the middle of each side of the square, perpendicular to that side.

Once this made, tie together those pieces, like the drawing shows.

You should tie well and with a solid rope.

Once you have finished tying the net together, you can lift it into its final place and fix it well to the support on the wall.
A beam or a beam-net should not be posed directly onto the wall. It should rest on a long piece of wood which distributes, like a cushion, the weight of the wall.

Those pieces of wood don't need to be strong, as they rest on the wall all their length.

They will be fastened to the wall with iron clamps, or with bows made in bamboo or in twigs.

Once the beams, or the beam-net are fixed

A cover can be posed which can be made with mats, twigs or other similar material.

On that cover should be smeared a thick layer of mud, which seals the interstices in the mat and makes the roof more solid.
This roof is good, but still not waterproof.

You should therefore cover it with watertight material:

Aluminium foil, plastic foil, or similar.

This kind of material can be fixed by glue on mats, laid on the top of the roof.

It is advantageous to have the whole roof tilted at a gentle slope, to allow the water to run off.
SPACE FRAMES
If you only dispose of small lengths of wood to build your roof, you can build a structure solid enough even for a large span.

For this purpose, you should make with that wood, trusses, either plain ones or space-frames.

A truss looks like a sort of a grid with triangular holes.

The simplest truss is that used for traditional roofs in many regions. Trusses with more meshes need shorter pieces of wood than do traditional roofs.

Besides that, such trusses don't need to be very high.
TO COMPOSE SUCH TRUSSES FIRST YOU HAVE TO DRAW THE PATTERN ON THE GROUND.

THEN, ADJUST THE APPROPRIATE PIECES OF WOOD TO THE DRAWING.

AND TIE TOGETHER THOSE PIECES WITH A VERY SOLID ROPE.

THEN YOU CAN LIFT UP THE STRUCTURE AND USE IT AS AN ORDINARY BEAM.

SPACE FRAMES ARE NOT VERY DIFFERENT FROM ORDINARY TRUSSES.

YOU CAN MAKE A SPACE FRAME TRUSS BY FIXING TOGETHER SEVERAL PLANE TRUSSES, LINKING THEM WITH APPROPRIATE PIECES OF WOOD.

THE LINKAGE SHOULD BE MADE SO THAT NEW TRIANGLES ARE FORMED IN ALL THE PLANES.
SPACE FRAME TRUSSES ARE VERY STRONG

AND THEY WEIGH LESS THAN FULL BEAMS DO.

THEY CAN BE BUILT WITH VERY SMALL PIECES OF WOOD

AND BEAR THE LOAD THAT A FULL BEAM WOULD BEAR.

IT IS LIKE A BRIDGE.

IF SUCH SPACE FRAME TRUSS IS MADE HIGH ENOUGH FOR A MAN STAND UP INSIDE,

IT CAN FORM AN ADDITIONAL STORY TO THE HOUSE.

indeed, THE COVER CAN BE FIXED ON THE UPPER RIM OF THE TRUSS.

AND A FLOOR ON ITS BOTTOM RIM.
Such a space frame structure does not need many supports, even for a large area, it does not need to on the walls either.

4 posts are enough to bear it.

If these posts are solid, the roof will stand even if the walls crumble (for example, in case of flood).

A space frame structure of this kind is earthquake safe, as it does not break when trembling, to make it completely safe.

It should not rest on ordinary posts (which collapse), it can rest directly on the ground, without foundations, or be supported by pyramid-like pillars, solidly tied to it.

It will be, then, as solid, as a table, which does not break when moved.
BAMBOO DOMES
WITH SUSPENDED MAT COVER

BASIC RESEARCH: YONA FRIEDMAN, EDA SCHAPP, CCSK
To make a cheap and efficient roof out of bamboo.

We started by making a frame.

A square with diagonal bracing near to its corners.

This frame, made of bamboo or of casuarina, was made of rods fixed together by ropes.

On this frame as a basis we erected a dome.

By making arches out of split bamboo or of full round bamboo.

These arches were about as high as the half of one side of the frame.

We fixed them standing up between corners of the frame, in various patterns.
Such arches can be laid out on the frame in many ways:

Like this:

There are many other patterns, like this one:

Or this one:

Where some arches start from the sides of the square and not from the corners.

Where they link each corner of the frame to the other 3 modules away.

We repeat this operation from each corner.

Or this one:

And many more. We made use for this museum of 6 different patterns.
To make sure that the assembled arches keep standing up from the start,

we choose to start with these 2 arches which form a cross on the octagon of the frame.

Or, in another pattern, those which lean on each other, and we tied together these 2 arches.

Then we repeated this operation starting, one after the other, at each corner of the frame. All 8 couples of arches were, at the end, tied together.

Once these main arches formed the dome shape we wanted

we had to fix that shape so we made 8 other arches, half as high as the main ones, each starting from a corner of the frame.

Linking it to the after-next one.

At this stage the dome structure became stable.
Another type of dome we started with a ring fixed on a pole.

As high as the dome should be.

We tied to that ring two bamboo rods linking it to a corner of the frame so that they should touch the ring on opposite sides.

And we repeated this from each corner of the frame.

We stiffened that dome, once all the ribs were in place.

With bamboo rings at various heights: one at the top.

One at mid-height, and so on.

Once we finished all these, we made low arcs between corners of the frame and tied these arcs to the ribs.
These dome structures are used to support a light lower dome which is more flat, and which is fastened on another frame, and which hangs on 4 wires from the upper dome.

The lower dome is the support of the roof cladding.

We made the roof cladding with bamboo mats.

A first layer of which was posed on the grid of the lower dome.

For the second layer, we prepared other mats on which we previously glued thin aluminium foil (on their upper side).
ANOTHER KIND OF CURDING (ALSO WITH ALUMINIUM FOIL)

CAN BE MADE BY FOLDING THE FOIL BETWEEN 2 BAMBOO MATS (WHICH PROTECT THE FOIL).

THE UPPER DOME HAS A DOUBLE TASK:
TO SUPPORT THE LOWER DOME WHICH HANGS ON IT
AND WHICH WOULD COLLAPSE WITHOUT THAT SUPPORT.

SUCH "SANDWICH" MATS WE PREPARED ON THE GROUND.

THEN WE FIXED THEM ON THE LOWER DOME, AS WE DID WITH THE ORDINARY MATS.

AND A SECOND TASK: THE UPPER DOME IS COVERED WITH FLAT ROUND BASKETS WHICH CAST A EIGHT-HALF-SHADOW OVER THE LOWER DOME, KEEPING ITS SHELL COOLER.
The aluminium foil has the property to reflect heat.

Thus it helps to keep cooler the room under the shell.

One can use plastic foils instead of aluminium.

It is cheaper (somewhat) and easier to obtain.

The half-shadow cast by the upper dome increases the cooling effect.

And the air current which can pass under both domes adds to that effect too.

It might be easier to work with them too.

But their cooling capacity is much less.
That more can rest on the wall.

But it might be better if it were supported by a posts or bamboo.

When you have finished to build the kind of roof on the ground, you can lift it into its place with a whole group of people. Lift it with ease.
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE

UNDER THE AUSPICES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

33, BD GABRIELLI, 75015 PARIS  ☎ (33) 783-20-24

LATITICE DOMES
There is an easy way to build a lattice dome:

It is a very strong structure making use of little material,

and it is not imply too much site work.

In order to build such a dome, you have to start with a rigid frame, which follows the outline of the house you want to build.

In order to make that frame rigid, you have to strengthen the corners of it, for example, with diagonals.
AFTER YOU BUILT THE FRAME, THE NEXT STEP IS TO COMPOSE, FLAT ON THE GROUND, THE LATTICE.

YOU CAN MAKE IT FROM WOOD, FROM SPLIT BAMBOO OR SIMILAR MATERIALS;

THAT LATTICE HAS TO BE ABOUT 3/4 LARGER THAN THE FRAME.

ITS MESHES CAN BE ABOUT 1 TO 1/4 FEET WIDE.

ONCE YOU FINISHED COMPOSING THAT LATTICE YOU SHOULD LIFT ITS CENTER AND FIX ITS ENDS (WHICH HANG FREELY) TO THE RIGID FRAME.

WHEN THE RESULTING LATTICE POUE IS WELL FASTENED, YOU SHOULD INTRODUCE DIAGONALS INTO ITS MESHES.

FIX THEM TO THE LATTICE.

THE RESULT WILL BE A VERY SOLID DOME.
BULB-SHAPED DOMES

BASE RESEARCH: EDI SCHAUER, IL, STUTTGART
Support structures for domes with suspended roof-skin can have diverse shapes.

Like simple spheric domes, rotational hyperboloids,
or more complex shapes like "space chains" (domes made with rings)

And domes of multiple curvature.

In this latter group bulb-shaped domes are among the most interesting.

The bulb shape is characterized by one curvature (the bulge) at the bottom half.
And another, opposite, one (the counterbulge) in the upper half.

That kind of double curvature comes from bending a rod in a particular way.
In order to build a bulb-shaped dome, you have to start with a rigid frame serving as the base.

This step is usual when building domes. That frame can be polygonal or circular.

You should dispose, on the ground, around that frame, the rods which will be the ribs.

Fix those ribs to the frame, then bend them upwards till their ends meet in the axis of the future dome.

Tie these ends together.

The dome, at that stage, will seem rather unshapely.

You should fix to the ribs two belts, which will start to define the final shape.

One belt at the upper part of the bulge.

The other one above the counterbulge.
Even at that stage the dome will have only an approximative bulb shape.

You have to force the ribs into the right shape by tending them with strings.

One string will define the bulge.

Another one the counterbulge.

Once the dome got the required shape, thanks the strings.

You should prepare long thin bamboo strips, two for each rib.

Dispose those strips in spirals around the onion shape and fasten them to the ribs.

First the spirals one way, then the counterspirals the opposite way.
With those spirals fastened, the bulb-shaped dome becomes rigid and ready.

You don't need the strings anymore and can take them away.

The dome will keep its wanted shape and be very solid.

That dome can support easily the roof skin you will suspend on it, proceeding in the same manner as with other similar domes.

Your roof will look beautiful with such a dome, and your house will be easy to distinguish among the other houses.
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE
UNDER THE AUSPICES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

RINGS INTO ROOFS.
The roof is the most important part of the house.

It is the roof which shelters us from the rain.

And it is the roof what protects us from the sun.

The roof keeps us dry and cool.
It is important to know how to construct a roof.

A roof consists of two main parts:

A "skin," which does not let the rain or the sun in,

And a "skeleton," which is strong enough to keep the roof up.

Let us look first at the skeleton:

You start with the skeleton when building a roof.

The skeleton can be made out of heavy timber.

This is expensive

And difficult to build.
You can use lightweight bamboo, as well.

But bamboo is less strong than heavy timber.

Trusses of bamboo have to have certain form

In order to be strong.

Triangles made of bamboo rods, or figures composed of several triangles can be much stronger than a simple truss of timber.

You can build such triangular forms by fixing several bamboo rods by strings.

You can fix figures which are "plane" (so you can lay them flat on the ground when working on them).

Other figures are in "space"; you can never flatten them out.

Such figures are the elements for skeletons of roofs.
You can compose skeletons for rooks with bamboo rings as well.

You make such rings by bending bamboo in a circle and fixing the ends with a string, as basketmakers do.

You can fasten, still with strings, several such rings together.

You can string together several bamboo rings flat on the floor into a particular pattern.

Then you lift up slowly the central ring of this net and tend with another string the external part of the external rings.

When you have finished tending and to fixing the string the dome you have built will remain standing.
IF YOU WANT THE DOME YOU HAVE BUILT TO BE PARTICULARLY STRONG,
YOU SHOULD MAKE A FEW SMALLER RINGS AND FIT THEM IN THE VOIDS AMONG THE LARGE RINGS.

ONCE THE DOME IS IN POSITION (IF YOU DO IT EARLIER, YOU CANNOT GIVE THE DOME ITS SHAPE).

IT IS EASY TO BUILD SUCH A DOME-SKELETON FOR YOUR ROOF;
IT CAN BE ABOUT 4-5 METERS LARGE (WHEN RINGS ARE ABOUT 2 METERS IN DIAMETER).
YOU COVER THEN THE SKELETON WITH MATS, LEAVES OR STRAW.

IN THE WAY AS IS USUAL IN YOUR REGION.
Another technique could be to compose a continuous net out of rings not larger than one foot. This network can be made in several ways:

Each ring can touch 6 other rings, or it can be neighbour to 4 other ones.

(Exception those at the edge of the net, obviously).

The rings can be all the same size, or different sizes.

You can bend or fold this network into many shapes:

You can make a vault, or a sort of a cone, or even a dome.

All these structures will stand.
IT COULD BE ADVANTAGEOUS IF, INSTEAD USING A SIMPLE RING

YOU WOULD USE FLAT ROUND BASKETS OF WHICH THE BAMBOO RING COULD REPRESENT THE RIM.

THUS, YOUR VAULT, OR CONE, OR DOME OR ANY OTHER SHAPE YOU MIGHT CHOOSE

WILL BECOME MORE STURDY

AND WILL FORM A SURFACE WITH INTERSTICES

INSTEAD SIMPLY FORMING A NET.

IF YOU CAN OBTAIN SOFT PLASTIC SHEETS (AS USED FOR WRAPPING OF MANY PRODUCTS)

AND COVER YOUR ROOF MADE OF BASKETS WITH IT.

YOUR ROOF WILL BECOME WATERPROOF, AND THE PLASTIC SHEET WILL LET THROUGH THE LIGHT AT THE INTERSTICES BETWEEN BASKETS.

IF YOU WANT TO PRESERVE THE PLASTIC YOU SHOULD PROTECT IT AGAINST HARD SUN, BY KEEPING IT IN SHADE.

YOU CAN COVER A ROOF MADE OF BAMBOO RINGS BY ANY LIGHTWEIGHT MATERIAL OF ROOFING YOU ARE USED TO USE.

THE RINGS AND THE FLAT BASKETS WILL SERVE AS A SOLID SUPPORT FOR THE ROOFING MATERIAL

YOU MIGHT CHOOSE.
STRUCTURES MADE WITH RING-BAUS

BASIC RESEARCH: YONA FRIEDMAN, CCSK, PARIS
One of the simplest structure, made with rings.

In order to support a suspended roof skin.

Is made with ball-like configurations containing 12 rings.

These configurations are called "dodecahedra".

To build a dodecahedron you start with disposing 6 rings on the floor.

In a flower-like arrangement: one ring in the center surrounded by 5 other rings.

You tie tightly the "petal" rings to the central one.

Then you lift the "petals" till they form a cup-like figure.

Then tie them in that position.
IN ORDER TO BUILD A DODECAHEDRON
YOU NEED 2 SUCH CUP-LIKE FIGURES.

YOU SHOULD LEAVE THE FIRST ONE ON THE GROUND, IN A CUP-LIKE POSITION.
THEN YOU LIFT THE SECOND CUP AND POSE IT, UPSIDE DOWN ONTO THE FIRST CUP.

IT IS IMPORTANT, THAT EACH PETAL OF THE UPPER CUP SHOULD BE FITTED INTO THE HOLLOW BETWEEN TWO PETALS OF THE LOWER CUP.

YOU SHOULD THEN TIE TOGETHER BOTH CUPS, BY THEIR PETALS.

THE RESULTING BALL WITH 12 FACES WILL BE A DODECAHEDRON.

YOU CAN BUILD DOME-LIKE STRUCTURES WITH THOSE BALLS.
FOR EXAMPLE, YOU CAN FIT TOGETHER 6 SUCH BALLS,
ONE IN THE CENTER AND THE 5 OTHER BALLS FORMING A CROWN
FASTENED TO THE 5 RINGS OF THE BELT MAKING UP THE LOWER CUP OF THE CENTRAL BALL.
THAT STRUCTURE WILL BE FAIRLY SOLID.
You can build, in a similar way, crowns made of any number of 12-faced balls.

By tying those balls together to form a ring:

- 4 balls,
- 6 balls,
- 9 balls, or more.

The rings, balls, assembled into such configurations, will get deformed.

That deformation will tend the structure like a spring.

For that effect, it is necessary to care that the constituting rings should not be too weak (else they burst) nor too strong (else they don't get deformed).
You can try many combinations to build such structures.

For example, by inserting cubes (made with 6 rings) between any 2 dodecahedra.

You can add tetrahedra too (made with 4 rings).

These combinations will be particularly strong.

These domes built with rings will be supported by wooden posts (for example).

It is important that the domes should be fastened to the posts in spots where several rings meet and, if possible, where their tangent is near to vertical.

Thus, according the kind of the dome there will be 3, 4, or 5 posts.
Once the ring dome is fixed onto the posts, you can suspend the roof skin on the structure. A skin made, for example, with aluminium foil glued onto bamboo mats, which are fastened on a flexible bamboo grid, which hangs on ropes fastened to the ring dome. Such a structure is lightweight and does not need much material. It is easy and fast to build it, and, if the links are solidly tied, the structure can be particularly strong.
5 DODECAHEDRA
10 HEXAHEDRA
5 TETRAHEDRA
6 DODECAHEDRA
12 HEXAHEDRA
6 TETRAHEDRA
YOU WANT TO BUILD
A ROOF,

WHICH IS QUITE SIMPLE
TO DO WITHOUT SPECIALIST'S HELP

AND WHICH SHOULD BE INEXPENSIVE

C'EST TOUT
CE QUE J'AI

NOUS VENONS
ADMIREZ
NOTRE TOIT

YOU CAN START TO MAKE,
WITH SPLIT BAMBOO
OR WITH THIN BRANCHES,

RINGS
OF A DIAMETER ABOUT 3 FEET
(1 METER);

IF THE MATERIAL (BAMBOO OR WOOD)
IS NOT STRONG ENOUGH,
YOU CAN MAKE A RING
WITH A SMALLER DIAMETER

YOU SHOULD PREPARE
A CERTAIN NUMBER OF SUCH RINGS:

THE NUMBER WILL DIFFER
ACCORDING TO THE MODEL (SEE ANNEX).
To start with, you have to tie together 4 rings.

With wire or with a solid rope.

In order to do so, you dispose the rings on the floor, like on the drawing.

And you tie them together where one ring touches another.

Then you lift the 3 external rings, leaving the central one on the floor.

The rings which you have lifted will touch in pairs, altogether in 3 places.

Having them in this position, you should tie them together.

You obtain thus a rigid structure made with the 4 rings (a sort of a tetrahedron).

You should make 5 of them and dispose them in the pattern of a flower.

Then tie them together in the center of that pattern where the 5 tetrahedra meet.

Then, you start to tie together the other rings.

First those on the top, then those below.
You obtain by doing so a structure in the form of a " lentil."

This is a very solid structure:

One can build such lentils with 6 tetrahedra as well,

Disposed as in the drawing.

One has to squeeze them somewhat, in order to tie them together.

Let us continue

First, you should make 6 lentils (each with 5 tetrahedra, or 7 lentils, each with 6 tetrahedra, whichever suits you best).

You take the first lentil, which will serve as core,

And you fix on each of its downside rings

The upside ring of each of the other lentils.
YOU TIE THE 5 LENTILS ONTO THE CORE LENTIL.

THEN YOU TIE TOGETHER THOSE LENTILS IN EVERY SPOT WHERE 2 RINGS MEET.

OFTEN THE ELEMENTS OF THAT STRUCTURE HAVE TO BE DRAWN TIGHTLY TOGETHER TO AVOID GAPS BETWEEN RINGS.

THE TENSION THUS CREATED MAKES THE STRUCTURE MORE RIGID.

YOU OBTAIN THUS A VERY SOLID STRUCTURE WITH A SPAN OF ABOUT 18 FEET (6 METRES).

WITH VERY THIN COMPONENTS.

THIS STRUCTURE CAN BE SUPPORTED BY WALLS OR BY POSTS.
THE STRUCTURE WHICH YOU HAVE BUILT

WILL SUPPORT THE "ROOF-SKIN",

MADE WITH MATS, WITH PLASTIC FOILS OR WHATEVER YOU PREFER.

THIS "SKIN" HAS THE FORM OF A FLAT DOME WHICH WILL HANG ON THE STRUCTURE YOU BUILT.

THUS, USING LITTLE MATERIAL

YOU CAN BUILD A ROOF, WHICH IS SOLID AND WHICH PROTECTS YOU, EASY TO REPAIR, AND WHICH WILL LOOK "NICE".
Suspended roofs.
A roof cover can be supported by beams.

But it can also be suspended from.

In the latter case you can make an all-rope roof.

Making with solid rope a simple net

From which the roof cover will hang.

To suspend such a supporting net you will need, at least, 3 posts to which the net will be fastened.

The net can have a layout of concentric polygons, having as many corners as many posts as you intend to use.

The net will consist of these polygons, linked with diagonals according to the number of posts.

That net will look like a large spiders' web.
You cannot hang, without precautions, that net simply onto the posts:

It would draw, by its sheer weight, the posts inwards and make them collapse.

To counteract that force you have to fix the end of each rope to a solid anchor fixed into the ground (as you would anchor a tent).

Thus anchors have to be driven deep into the ground to avoid their slipping out or tearing away under the effect of the weight of the roof.
Once the suspension net firmly fixed to posts and anchors,

you should prepare the roof cover.

For example, with waterproof mats on a nearly flat lattice shell.

(Note: if the lattice is not flat enough it would be difficult to follow with mats, its form).

But, a nearly flat lattice shell is not solid over a large span (for example, one needed to cover a house).

Such a flat lattice shell can be solid if it is supported in many places either by posts or by suspension.

In the case we examine, it will be supported by suspension:

If the lattice shell with the mats is suspended in many places on the suspension net, it will be quite solid.
IT IS NOT DIFFICULT TO COVER THE LATTICE SHELL WITH MATS OR OTHER SHEET MATERIAL.

TO MAKE A ROOF FOR YOUR HOUSE.

THE LATTICE SHELL WITH THE MATS (COMBINED WITH WATERPROOF FOIL) WILL MAKE A SOLID ROOF EASY TO MAINTAIN.

OBVIOUSLY ENOUGH, SUCH A FLAT LATTICE SHELL CAN BE SUSPENDED FROM OTHER KINDS OF SUPPORTING STRUCTURES TOO: LIKE DOMES, ARCHES, OR SPACE-FRAME GIRDER.

A ROOF CAN BE SUSPENDED FOR NEARLY EVERY KIND OF SUPPORT.
If you want to build a suspended roof, without having to anchor it, you can suspend the roof on stiff supporting structures, like arches, domes, or space-frame girders.

A particular kind of space-frame uses little wood (or any similar stuff), substituting ropes for a part of the rigid members.

Such space frames are more complicated to build, but they are material-saving.
AN ORDINARY SPACE-FRAME CONSISTS, ROUGHLY, OF POLYHEDRA.

THE SIMPLEST TO DRAW IS A ROW OF CUBES, WITH THEIR DIAGONALS,

EITHER THOSE PLANE TO THE FACES, OR THOSE PASSING THROUGH THE INSIDE OF THE CUBE.

THESE SPACE-FRAMES, CUBES AND DIAGONALS, ARE MADE OF RIGID MEMBERS.

BUT, EITHER THE BOXES, OR THE DIAGONALS IN THE PLANE OF THE FACES COULD BE MADE WITH ROPES ONLY,

OR, EVEN THE DIAGONALS PASSING INSIDE THE CUBE.
Such "rope-and-rod" structures can well serve to support a suspended roof.

But it might be more practical, that the structure support the roof from beneath.

That kind of structure might be too sensitive to the weather, if above the roof-cover:

Below the roof, it is well protected.

If used beneath the roof-cover, the rope 'n rods structure can have a better adapted shape.

Made of cubes of slightly varying sizes:

Thus your roof will have the slope for the rainwater to run off.

In this case, the centre cubes will be slightly higher than those along the edges.
It is obvious that a roof can be made with a slope to one side only.

Then you don't need to make the girder itself sloping.

It is sufficient to have the bearing walls unevenly high.

You place the roof cover onto the slanted girder.

Slanted enough to make the water run down.
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE

UNDER THE AUSPICIES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

33, BO GARIBALDI, 75013 PARIS © (33) 783-20-24

FREELY SHAPEABLE GRIDS

BASIC RESEARCH: Y.S. LEBEDEV
LABORATORY FOR ARCHITECTURAL BIOMICS
MOSCOW
TO BUILD A ROOF ON AN IRREGULAR OUTLINE IS A DIFFICULT TASK.

IF TACKLED WITH ORDINARY TECHNIQUES.

IT IS POSSIBLE TO BUILD GRIDS OF A PARTICULAR KIND, WHICH CAN TAKE A WHOLLY IRREGULAR SHAPE, EITHER IN PLAN, OR IN SECTION (FOR EXAMPLE, COVERING BUILDINGS HAVING VARIOUS HEADROOMS);

SUCH SHAPES CAN EVEN BE ESTHETIC.

IRREGULAR SHAPES CAN BE VERY SOLID.

YOU CAN TEST THIS, EXPERIMENTALLY, WHEN COVERING A SPACE BETWEEN 2 BOXES WITH A SHEET OF PAPER.

IF YOU FOLD THE PLANE PAPER SHEET ONTO THE BOXES, THE SHEET WILL IMMEDIATELY SAG IN THE MIDDLE.

IF YOU BEND UPWARDS THAT SAME SHEET, LIKE A VAULT, IT WILL KEEP THAT SHAPE, PROVIDED THAT YOU FIX THE LOWER EDGES.

IF, ON THE OTHER HAND, YOU CRUMPLE THAT SHEET THOROUGHLY AND THEN DISCRUMPLE IT, THE SHEET WILL WORK AS A SOLID COVER.
A grid can work like that shape of paper did, if the grid bars are linked with soft joints.

You can build such a grid, for example, with long bars along one axis and short ones along the other one.

The joints linking the bars have to be soft enough to permit free movement of the bars.

For example, the bars can be linked with ropes or similar soft material.

Such a grid can be deformed into an irregular shape and remain solid.

The main conditions concerning the solidity of the grid are the following:

First of all, the grid, laid out flat on the ground, has to be larger than the area the roof should cover.

Secondly, the outer edges of the grid, once in position, should be solidly fixed.

Third, the crumpled shape of the grid should have more "mountains" than "valleys."
It is easy to make such a grid with bamboo.

First, you cut the bamboo into pieces of appropriate length: short ones and long ones.

You pass then a piece of rope through each piece of bamboo,

leaving enough length of rope at both ends of the bamboo piece

To tie the pieces together.

Once these preparations are done you start to tie together the pieces into a grid.

According the pattern in this drawing:

Short pieces in a line, long pieces alternating.

Once the grid is knotted together,

you can form it into various shapes.
That particular grid is one of the simplest. There are many other grids which behave in a similar way:

**Grids made with pentagons**
(5 edges)

**With hexagons**
(6 edges)

**With heptagons**
(7 edges)

... etc.

Their common property:
All of them have soft joints
(at least a part of their joints).

You can thus combine stiff joints and soft joints into various patterns.

All of these grids can be adapted to particular roof shapes.

But the simplest one is the one explained before in detail.

And is the most practical one.
IT IS EVIDENT THAT THOSE POLYGONS FORMING THE GRID CAN BE SUBSTITUTED BY RINGS.

ONE CAN MAKE EQUIVALENT GRIDS TO ALL POLYGONAL PATTERNS BY USING RINGS, EVENTUALLY OF DIFFERENT SIZES.

TO BUILD SUCH A GRID, TAKE THE RINGS AND LAY OUT AN ARBITRARY PATTERN WITH THEM.

THEN FIX THOSE RINGS AMONG THEM.

EITHER WITH SOFT JOINTS (IF THE RINGS ARE RIGID) OR WITH RIGID JOINTS (IF THE RINGS ARE FLEXIBLE).

YOU OBTAIN A GRID, WHICH WILL BEHAVE THE SAME IN THE SAME MANNER AS THOSE MADE WITH STRAIGHT BARS (WHICH WE DISCUSSED BEFORE).
DOME STRUCTURES FOR FLEXIBLE MATERIAL
If you only have soft and flexible stems available, you can still use them for a roof building a very particular kind of dome.

That dome consists of large and flexible rings.

Each ring having a diameter slightly larger than half the span to be covered.

You will need, for that dome, a dozen or more of such large rings.

And, also another ring, a small one, having a diameter of about 1/4 of that of the large rings.

All these rings are not necessarily very stiff, but rather elastic.
You should design the layout of the dome on the ground.

Place the small ring in the centre.

And you should dispose the large ones like the petals of a flower around it.

The small ring being inside the larger ones.

But take care, that each large ring should cover, on one side, its neighbours.

And be covered by them the other side.

When all the rings are thus in place, you should fasten all the large rings in that position to the small ring in the center.

This fastening can be done with a piece of rope, or with wire.

Wound around the central ring and the part of the large rings which touch the small ring.

Once the "flower" is tied together in its center.

You should lift the central ring up from the ground.
You should lift that ring to a height, that the "flower" should form an inverted cup.

You have to keep the central ring in that position with a heap of stones (for example).

And start to tie together the large rings in all the spots where they touch each other.

Tie them well!

To avoid the joints slipping out of place.

Once you have fastened all these spots you can take away the scaffolding (that heap of stones):

The dome will keep its shape.

It can bear the roof-skin.

If you want to reinforce that structure, one or two big rings applied mid-height will do the job.
Another way to make such a dome is through making a "Borromean" loop.

To do this, start with (for example) 5 rods, put on the ground around a central ring.

Then bend them, making their ends meet.

Once the ends met, on the ground, connect them.

When you lift from the ground the central ring, you got a "Borromean" dome.

A variant to this is called a "Cyclic Knot".

To build it, start again with 5 rods, putting them around the central ring.

Bend them, and bring together the ends, approaching the ends of neighbouring rods to meet.

Connect those ends, lift the core ring.

And your dome is ready.
COMMUNICATION CENTRE
OF SCIENTIFIC KNOWLEDGE FOR SELF-RELIANCE

UNDER THE AUSPICES OF THE UNITED NATIONS UNIVERSITY
WITH THE PARTICIPATION OF THE INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

BUILDING WITH GRASS
Grass can be an important building material.

It can serve, first of all, for roofs:

Grass bundles pointing downwards allow the rainwater to drip down.

Grass can be a heat insulator as well, keeping the inside of the house cooler, or warmer, according to the season.

Bundles of grass can be used thus as a coat, protecting the house or its parts against rain, temperature and sunshine.

But grass bundles can be strong enough to form the skeleton of the house.

If one makes a bundle of strong grass tied together with string (which too can be made of grass), one can make them very long if each length of grass in the bundle overlaps the next layer for about a third of its length. Such a grass bundle can be very resistant if it is thick enough.
A very thick grass bundle works like a bamboo cane.

But the bundle is much heavier than the bamboo.

A grass bundle works better when bent,

than it does when straight.

The simplest way to use grass bundles is to make arches out of them.

A bundle - arch is quite resistant.

Putting a number of such arches side by side in a row can make quite a good roof.

Obviously, you have to fix the arches to one another by transversal bundles.
A different type of arch can be made when you make stand two bundles of grass at a small distance between each other, making the upper ends meet, and then tying them together.

If you make, for example, four of such arches, then you start four smaller ones from the point of the lower ones, and so on, till you get a sort of a conical roof.

Another roof type can be made of grass-rope (we call grass-rope long thin grass bundles). If you coil such a grass-rope like a snail's shell, making the coils smaller and smaller as you go higher, you get thus a sort of a dome or a conical roof.
You should, when building such a roof:

Use some twigs or thin bamboo, to define the shape of the dome:

The job of coiling the rope, is made easier.

And strengthens the dome.

For resisting the wind.

If you make a "hairy" grass rope, the hairs of which point downwards, and you coil this hairy rope around your roof, conic or domed, your roof will be better protected against rain.
Grass can be good food for your cattle,

It can be a good material to make household utensils with,

And finally, it is a good building material.

To make grass grow on otherwise useless land can provide an important resource.