
BUILDING WITH FIRE
The Pioneering Work of
Ray Meeker

RAY MEEKER’S PERSPECTIVE

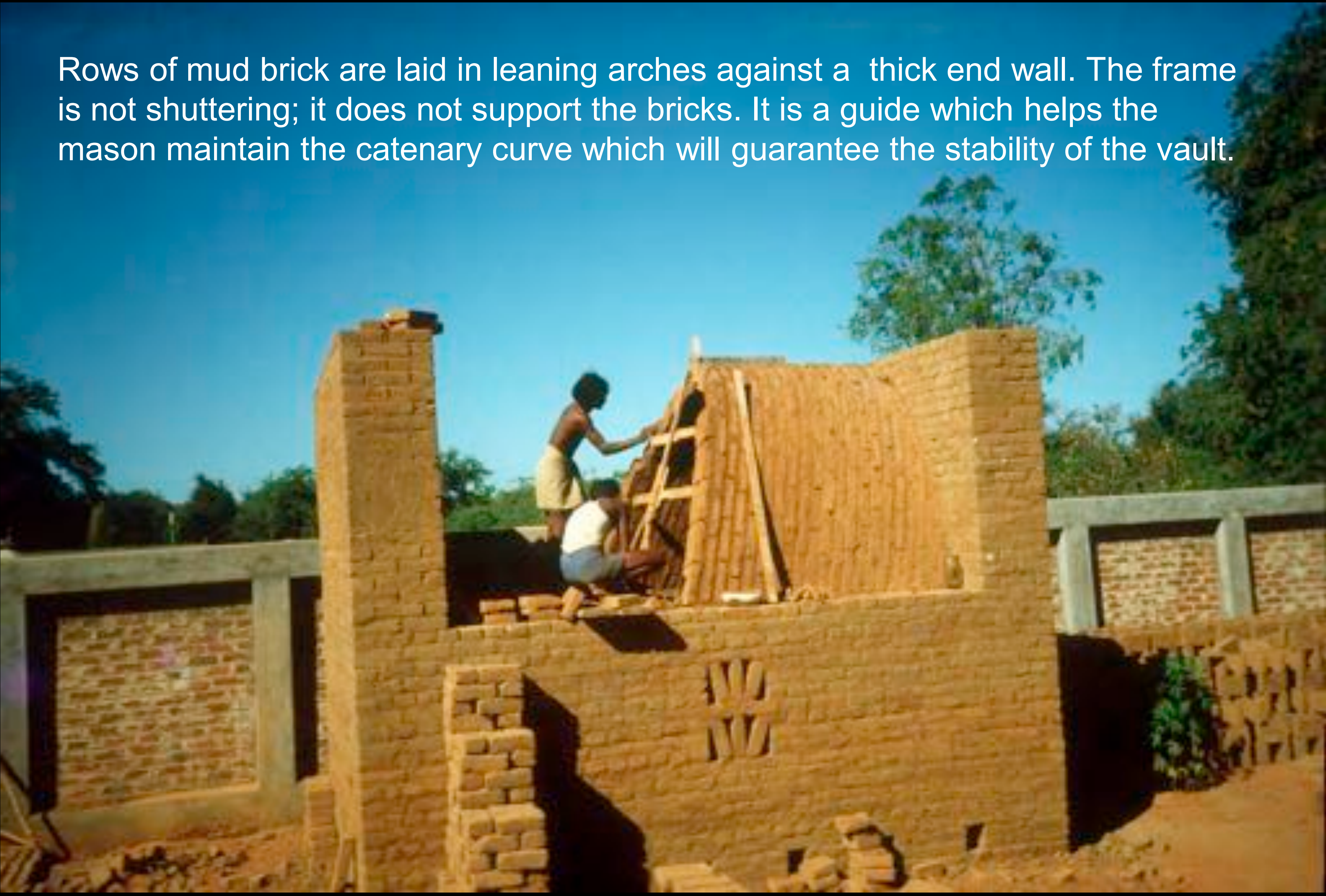
This presentation documents my experiments with stabilizing mud brick structures by firing in situ. This technique was originally conceived by the late Iranian architect Nader Khalili.

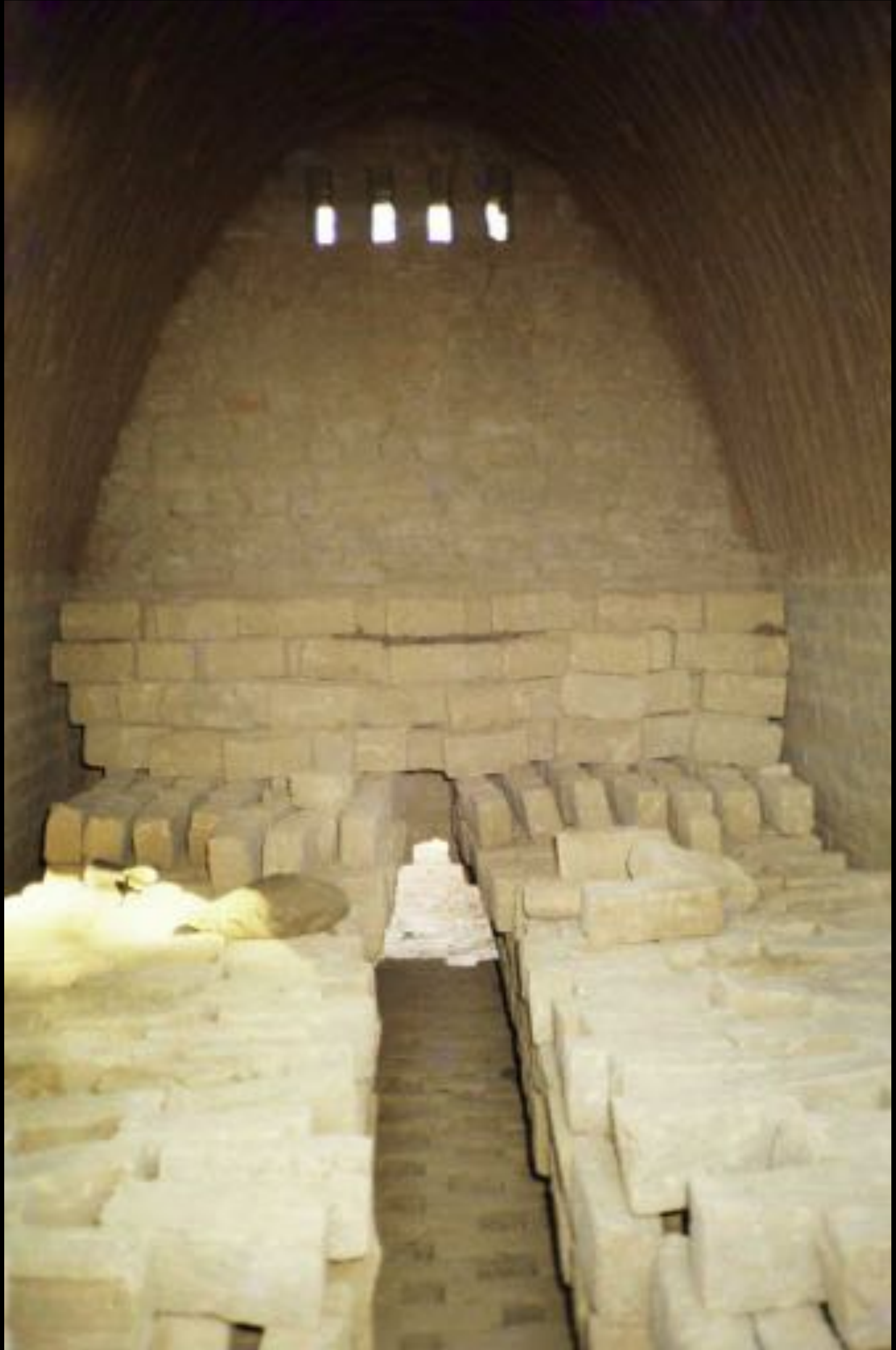
I spent thirteen years with this unusual process, working towards an affordable, environmentally friendly house.

With my university background in architecture and ceramics, this was an obvious fit. In 1984 on a trip to the US I attended a two-day workshop with Nader Khalili, and in 1985 I built my first test structure.

First test. A small vault, 3 m long with a 2 m span on a shallow foundation of fired brick in lime mortar.

Rows of mud brick are laid in leaning arches against a thick end wall. The frame is not shuttering; it does not support the bricks. It is a guide which helps the mason maintain the catenary curve which will guarantee the stability of the vault.





Loading the kiln/house with brick and tile. Three channels are provided for wood stoking.

Lighting the first firing with Dutch ceramic artist Jan de Rooden, who was funded by the Dutch government to participate in the first experiment.

This vault is insulated by 10 cm layer of ash and clay. Fired with wood, the house is now an up-draft kiln nearing 900 degrees centigrade, the peak temperature, after 24 hours of firing.

The brick kiln finished as house. Tiles fired in the structure are laid over the vault for additional water-proofing. Lime plaster on the wall and fired brick cornices on the vulnerable horizontal surfaces complete the finishing.

The wall is thick and fired only half-through. The outer layer of mud brick absorbs water from the ground and separates from the fired inner layer.

Test two is a 5 m long vault, with a 3 m span. Walls are thick. 45 cm.  I make a composite wall with a fired brick skin.

Before Jan went back to Holland he urged me to try a more open vault profile. I agreed, but deviated no more than 5 cms outside the line of pure compression described by the catenary.

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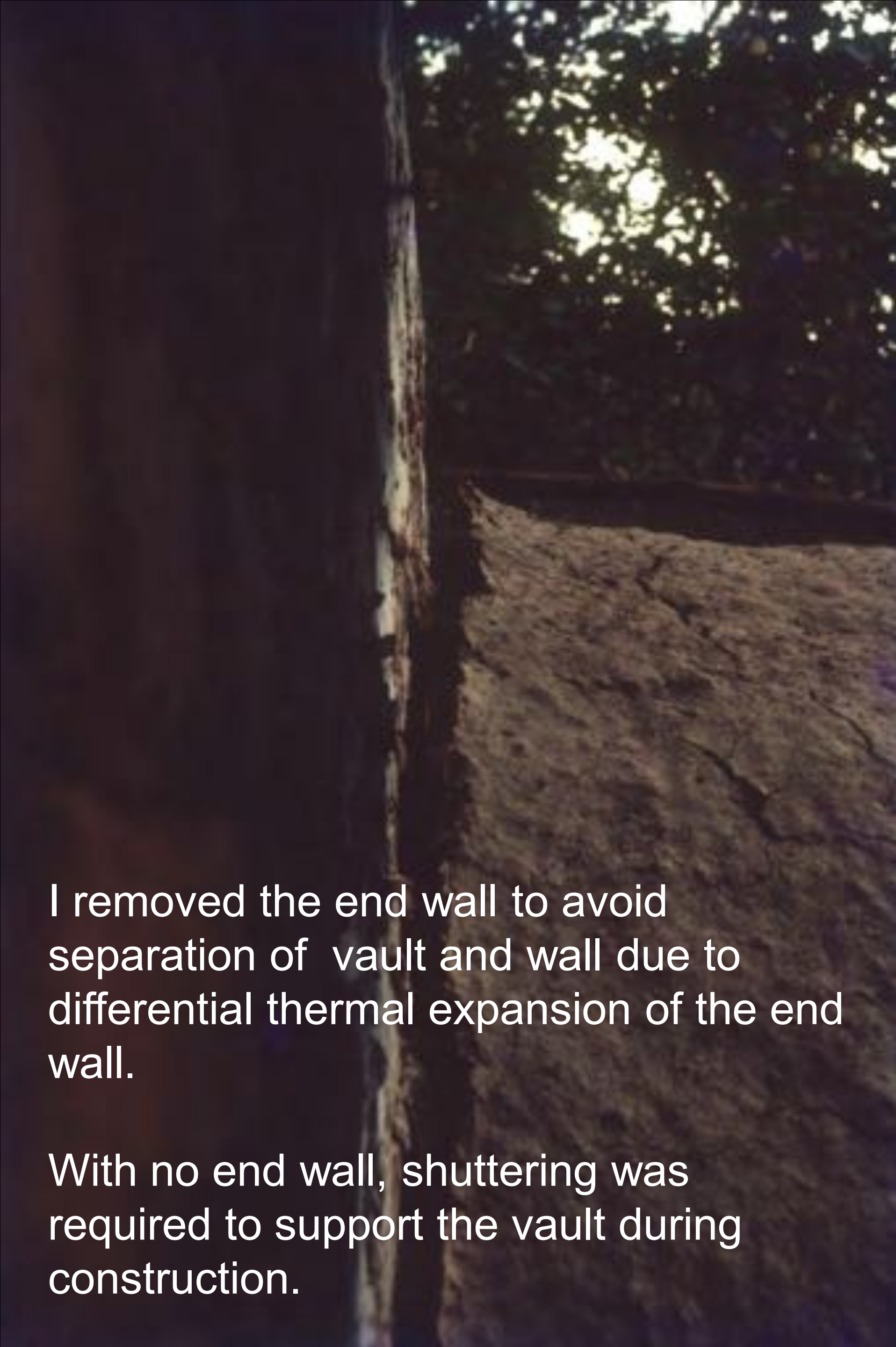
I noticed a crack opening up on the inside of the second test vault about two months after it was fired and finished. A visiting foundry engineer pronounced the structure safe.

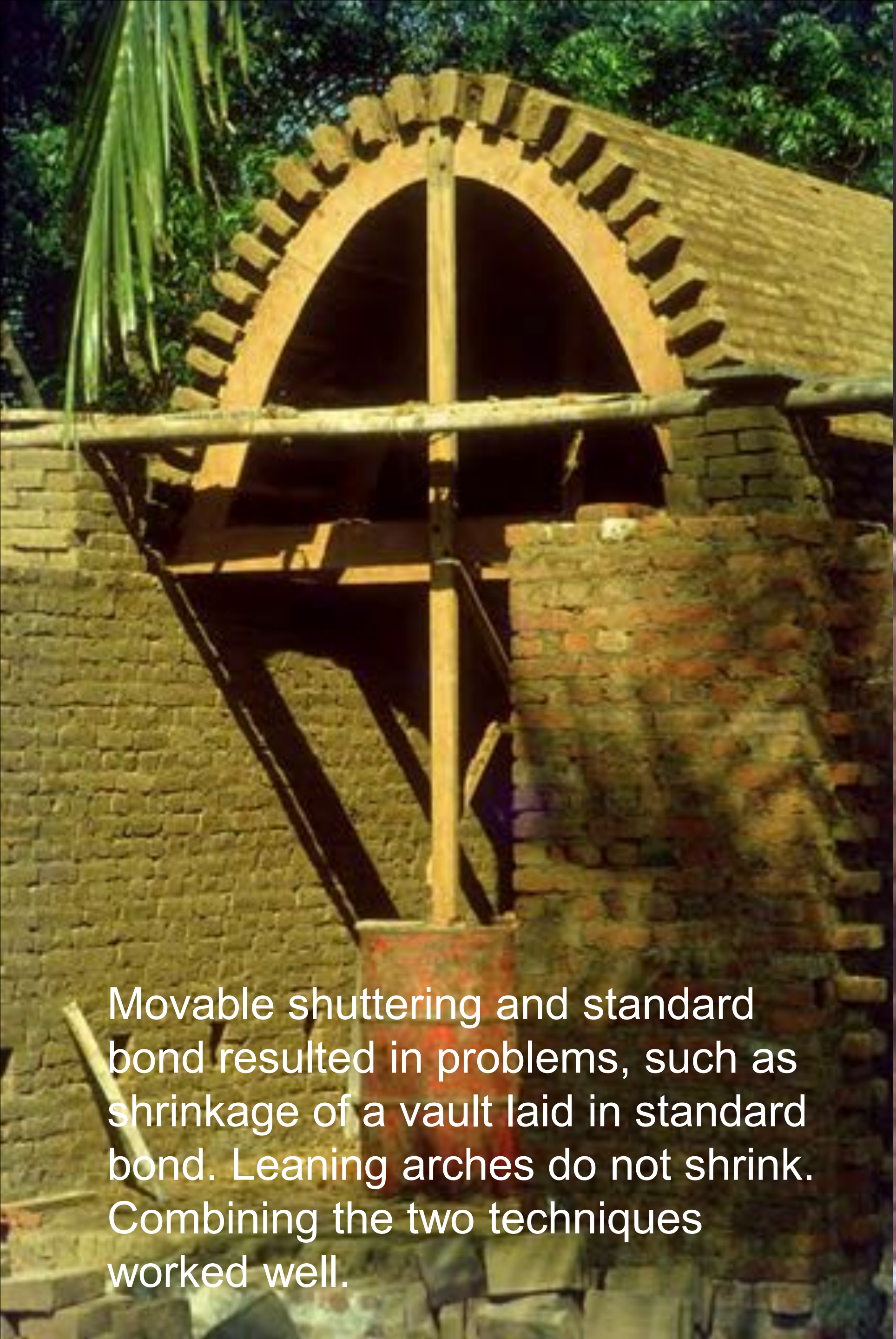
I went inside to photograph the crack and the next thing I knew I was on the ground outside the collapsed vault. My camera was underneath it. My mason had noticed the beginning of the vault collapse and he had pulled me out.

Since then, all vaults have been catenary!

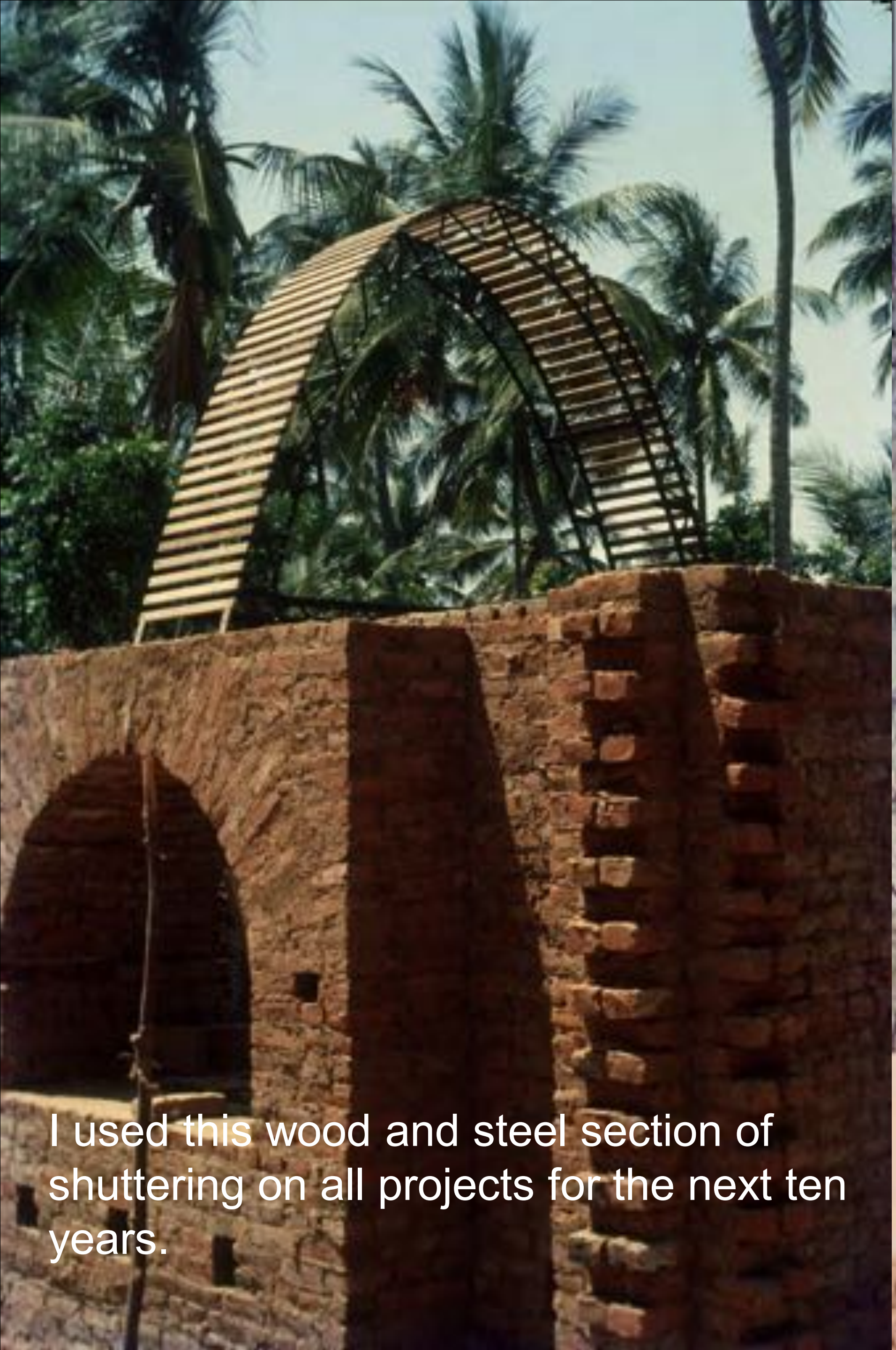


I removed the end wall to avoid separation of  vault and wall due to differential thermal expansion of the end wall.

With no end wall, shuttering was required to support the vault during construction.



Movable shuttering and standard bond resulted in problems, such as shrinkage of a vault laid in standard bond. Leaning arches do not shrink. Combining the two techniques worked well.



I used this wood and steel section of shuttering on all projects for the next ten years.

Test three. 1986. Brick making in the GBP compound. The idea of digging a hole in the ground, making mud bricks, building a structure and firing it, then transforming it into a house with some form of water-proofing has an undeniable, if romantic, appeal. In fact, most clays do not make a good fired brick. On-site clay is key to the economics of the process. Transport of clay for bricks or purchase of ready-made raw bricks is expensive.

# MOVING TECHNOLOGY

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SOME POLICY ISSUES FOR RURAL HOUSING IN INDIA TODAY

THE ROOFING ELEMENT IN LOW COST SHELTER CONSTRUCTION IN RURAL AREAS

COMPREHENSIVE HOUSING ON EDURUMONDI ISLANDS: COASTAL ANDHRA PRADESH

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# FIRED HOUSES: A CONCEPT FOR STABILIZING EARTH STRUCTURES

***The need for low-cost houses in the rural areas is mounting. Costs, however, are on a steady and unrelenting rise and natural resource reserves are fast declining. In this context, a unique technique to improve mud houses by firing offers a new hope to the solution of the housing problem. The author, a ceramic expert with an academic background in Architecture, describes the new concept and technique in detail.***

Ray Meeker*

A good deal has been said over the past fifty years on the need for a revival and/or upgrading of mud building technique in order to produce a durable "low cost" house. The call, strident in the past decade, as housing demand increases, energy costs rise and natural resource reserves seem to be on decline, has yet to yield a totally satisfactory solution. To be sure, there has also been strong opposition to mud as a viable material for building in the twentieth century. The resistance, not unjustified, stems from technical, cultural, and no doubt political and economic prejudices. Without getting bogged down in mud vs. cement rhetoric, it should be sufficient to say that any technique which might produce a reasonably low cost solution to today's housing shortage is certainly worth serious investigation.

The Iranian architect, Mr. Nader Kahlili, has pioneered a method for "stabilizing" mud structures. In his book *Racing Alone* (Harper and Row, 1983) he relates his five-year quest for a technique to improve the village house, which culminated in the firing of an existing house and subsequently the building and firing of a ten-room school.

To me as a potter – with a university background in Architecture – and living in India – a country with both an acute housing shortage and a tradition in mud building – Mr. Khalili's experiments hold a special appeal.

**Without getting bogged down in mud vs. cement rhetoric, it should be sufficient to say that any technique which might produce a reasonably low cost solution to today's housing shortage is certainly worth serious investigation**

In 1985, with the assistance of Mr. Jan de Rooden, a Dutch ceramics artist, who was funded by the Dutch government to come to India as a consultant to the project, I began a series of experiments which hopefully will lead to both a technically sound and economically viable stabilized mud structure.

## Essential Process

The fired earth house concept is both simple and potentially revolutionary in its economic implications.

Stated in its most fundamental terms, the process is as follows:

- Build a room/kiln in unbaked mud brick. The roof can be either vaulted or domed.

- Fill the room/kiln with a product; i.e. bricks, tiles, drain pipes, etc. and fire to between 900 and 1000°C.

- Use a portion of the product for finishing the house – tile the roof and floor, build a small compound wall with the bricks, etc.

- Sell the remainder of the product to recover as much of the building cost as possible.

With the right product, at least in theory, the building could cost nothing. I suppose in theory it could actually earn, but to date I have only spent!

* *Ray Meeker, Golden Bridge Pottery, Pondicherry*

**Brief Description of Experiments Conducted to Date**

Four vaulted structures have been built and fired, varying in size, construction and/or firing technique.

Structure No. 1 – A vault – 2 m. span, 1.35 m. rise, 3 m. long on 1.65 m. high walls.

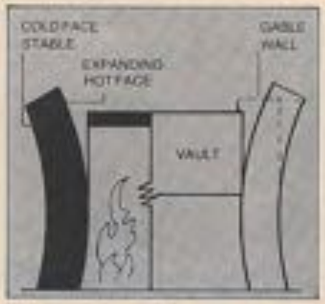
The aim of this structure was to learn how to build a "Nubian" vault without centering and test its behaviour in firing. It held 4,500 bricks and 1000 small tiles which were laid over the vault after firing. It was fired with wood to 960 °C in a 40-hour cycle. The exterior of the vault was insulated with a mixture of clay, ash and sand in a 10 cm. thick layer. The bricks were actually superior to most bricks made in our area. The vault, however, was really not sufficiently stable on the exterior. The walls, of course, though well-burnt on the inside, were absolutely untouched on the exterior.

The most significant reaction of the structure to the firing process was the separation of the gable wall from the vault. Interestingly, this in no visible way affected the integrity of the vault.

This separation is caused by differential thermal expansion.

As the interior of the structure reaches temperature of 850 to 1000° C, there is significant expansion of the walls, but on the inside only. The exterior, being cold, is not expanding. This causes the walls to bow and lean out of plumb, separating altogether from the vault. Though the gable walls move back on cooling, they do not return to their original plumb position.

Structure No. 2 – A vault – 3 m. span, 2 m. rise, 5 m. long on 2 m. high walls. Insulation of vault as in Structure No. 1.




This structure was large – certainly, at 4 m. interior height, much larger than necessary. The aim, however, was to test a structure with both a significant carpet area and a height which would make possible the addition of a loft after firing. One wall was opened with two large arches in order to see the potential for connecting a series of vaults with very open passage between.

As previously mentioned, exterior walls remain untouched by fire. Though a number of methods for stabilizing a mud wall with plaster exist, I opted for a composite wall in this test. The walls, being very thick (45 cm.) were built with a fired brick on the exterior, mud brick on the interior. Though this does raise cost somewhat, I believe the expense will be justified by the increased life span of the building.

This structure held 18,000 bricks and was fired to 940°C in 48 hours. The gable walls reacted in what has become a predictable manner. The exterior of the vault, though certainly improved in terms of fired quality, still showed large areas of unstable brick. The large arched openings showed what seemed to be minor cracks, but subsequently, with a very heavy monsoon, they proved to be disastrous.

Structure No. 3 – A vault – 2.25 m. span, 1.5 m. rise, 5.5 m. long on 2.14 m. high walls. Insulated with two courses of fired brick.

In Structure No. 3, a significant change in construction technique was tested. The gable walls were eliminated altogether in order to solve the problem of plumb. These end walls are then added in a fired brick after the completion of burning the building.

There are advantages as well as disadvantages to this. The end walls and their foundations can be much less massive. They are built in completely stabilized brick. However, this does necessitate the use of centering of some kind as there is no end wall on which to lean the vault, essential to the

Nubian technique. Vault No 3. was constructed over a moveable section of centering 1 m. in length. Though one can argue with the extra expense and complication of using centering, in fact it is an excellent way to maintain the catenary curve so necessary for the stability of the structure.

For firing, the open ends of the structure are temporarily filled with unfired brick. After firing, 1500 of these temporary "door" bricks were found to be well fired, and a very significant number were well fired on one end and were incorporated as headers in the exterior of the walls of Structure No. 4.

Structure No. 3 held 13,000 bricks and was fired for 78 hours. Though fuel consumption was slightly increased relative to the first two tests, the vault exterior shows much less unstable area.

Structure No. 4 – A vault – 2.25 m. span, 1.5 m. rise, 5.25 m. long on 2.14 m. high walls. Insulated with a combustible mixture of cow dung, straw and clay.

In this structure four technical alternatives were attempted and all proved valuable.

The side walls in the first three buildings showed a movement similar to, though less pronounced than, the movement of the gable walls. This movement was monitored in Structure No. 3 and in Structure No. 4 the walls were built out of plumb – leaning slightly inwards. After firing, the walls had moved, yet remained just out of plumb – *inward*.

The vault was built with a combination of techniques. A 75 cm. section was built over the frame approximately midway between the ends of the side walls. The vault was then continued with the Nubian method, leaning bricks against the 75 cm. section. The frame was again used to finish the vault at the ends.

In the first three structures the attempt was simply to insulate the vault. The fourth vault was covered with a combustible mixture of cow dung, straw and clay. This mixture serves as insulation up to a point – then ignites and contributes to the stabilization of the exterior of the vault. It was hoped that the mixture would not begin to burn until quite late in the firing cycle when the interior was reaching its peak temperature. This in fact was the case, and the vault cover continued to burn slowly for two full days after stoking of the fire was completed.

The result – Vault No. 4 is completely stable – inside and out. It should be noted that this could be achieved by firing the structure to a higher temperature on the inside, but as our local brick clays will not tolerate much over 950°C, this is not possible without weakening both structure and product.

The fourth technical improvement realized in this most recent attempt was in terms of the product. Again, 13,000 bricks were fired in this structure; however, 8,000 of these were table-moulded bricks of a relatively high quality. The sale of these first quality bricks brought a return of Rs. 6,300 on the structure. Though table-moulded bricks do cost more to produce, we did get a better return on the over-all cost of producing the building as all the other process costs remain unchanged. The sale of these bricks in no way covers building cost, but it does indicate clearly the potential that lies in product development.

The third and fourth structures are now in the process of being finished. End walls have been added and vaults and exterior walls are being waterproofed. It should be noted that though the vault is stable after firing (will not waste away), it is still quite porous and does require treatment in order to make it water resistant.

Vault No. 3 is being waterproofed

**The village potter, whose livelihood is now threatened by mass produced plastic and aluminium vessels, and whose knowledge and skill with earth and fire are no longer fully utilized, holds a great potential for creating a rural clay-based building industry.**

with a cement/lime/clay/sand mixture and Vault No. 4 is being covered with tiles.

The next step is to develop a plan for a low cost house. The structure will consist of four vaults in a series sharing common walls. Economy is gained in 3 ways:
1. by reduction of no. of walls,
2. by vaults supporting each other laterally, eliminating the need for side wall buttresses except at extremities, and
3. by reduction of fuel costs as heat is not lost through walls or, in the event that vaults are fired in series as in a continuous chamber kiln, hot blue gases from one room preheat subsequent rooms.

Two floor plans will be demonstrated. One plan, consisting of two vaults, one with a partial loft, will have a carpet area of 34 $m^2$. The second plan – a single vault with loft – will demonstrate a smaller solution of 24 $m^2$ carpet area. The fourth vault will be waterproofed but remain unfinished.

The unfinished fourth vault is to demonstrate the possible use of this method in a "site and service" scheme, where sanitation, water and one room are provided, and the occupant finishes the "room" and makes additions as his financial situation allows. In this system, a portion of the product could be included in the purchase price – bricks for a small compound wall, window jollies, floor tiles etc. The owner would then have to provide mainly labour to finish the house.

**Product Development**

Product development in the broadest sense has two main objectives. First and most immediate is to generate income from process and produce as many building components as possible necessary in the completion of the house. Secondly, though both ambitious and extremely optimistic in outlook, it must be at least postulated that a small scale, labour intensive, rural building industry, producing a wide variety of fired clay building components, is a possibility.

The village potter, whose livelihood is now threatened by mass produced plastic and aluminium vessels, and whose knowledge and skill with earth and fire are no longer fully utilized, holds a great potential for creating a rural clay-based building industry.

Here is a partial list of products planned for development in the next phase of testing.

1. Table-moulded bricks
2. Glazed facing brick
3. Terra-cotta and glazed tile
4. Drain pipes
5. Jollies
6. Toilet pan in glazed earthenware
7. Terra-cotta bio-gas plant and burner
8. Decorative and ritual elements of the house such as altar and deepam niches
9. Smokeless stove
10. The terra-cotta "refrigerator"

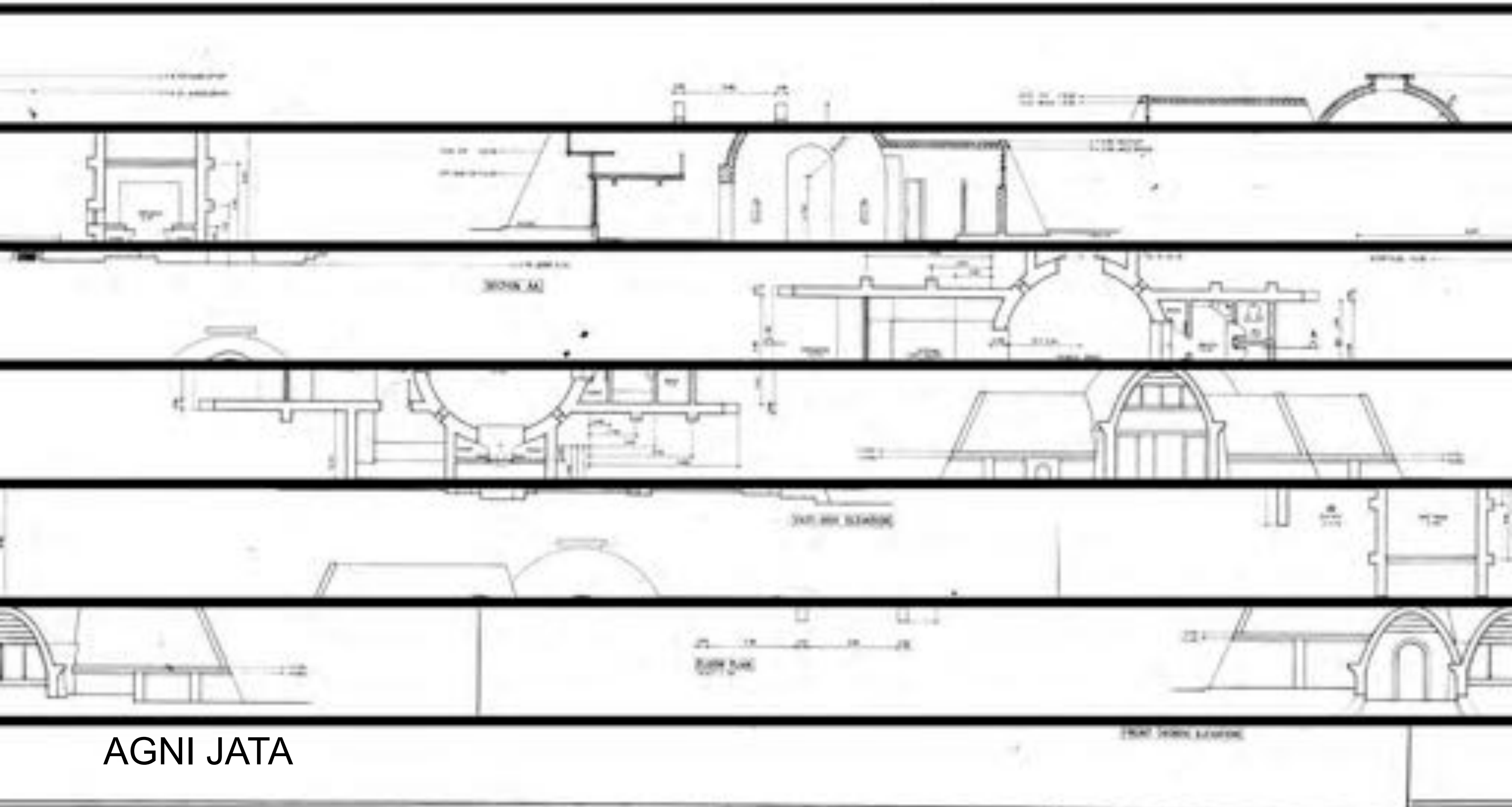
Whether or not the brick clay is on-site, a tremendous amount of space is required for a project like this.

In 1987 I was asked by two very brave Aurovillians to build them a fired house. Auroville, 10 kms north of Pondicherry, is a community where 2000 people from all over the world are conducting a living experiment in human unity.

I had been firing single vaults in my first six tests. The goal was to develop a small, inexpensive house for rural India. Though Dhruva and Mallika's requirements were modest, a single vault would not be enough. We decided on four vaults surrounding a 5 meter dome.

The vaults would be fired cross draft into the dome. The dome, with a central chimney,

A small fifth vault in fired brick was added after firing as an entry.



AGNI JATA

The house floor was set 75 cms below grade to eliminate as much buttressing as possible.

Foundations are in fired brick and lime mortar.

Structural bricks were made on-site with a mixture of site clay, a very sandy laterite, and clay from brick fields 20 kms  away. These are vault bricks, 25 x 15 x 5 cms.

A husband and wife team made 1000 bricks per day.

All mortar is the same mix of clay as the structural brick.

Mud brick begins three brick courses above the floor level. Experience had shown that the lower wall tended to be under-fired.

Four vault bands are laid over the vault shuttering.

A 15 cm thick mud vault section. 2 m high with a 3 m span.

Using the vault
frame as a guide.

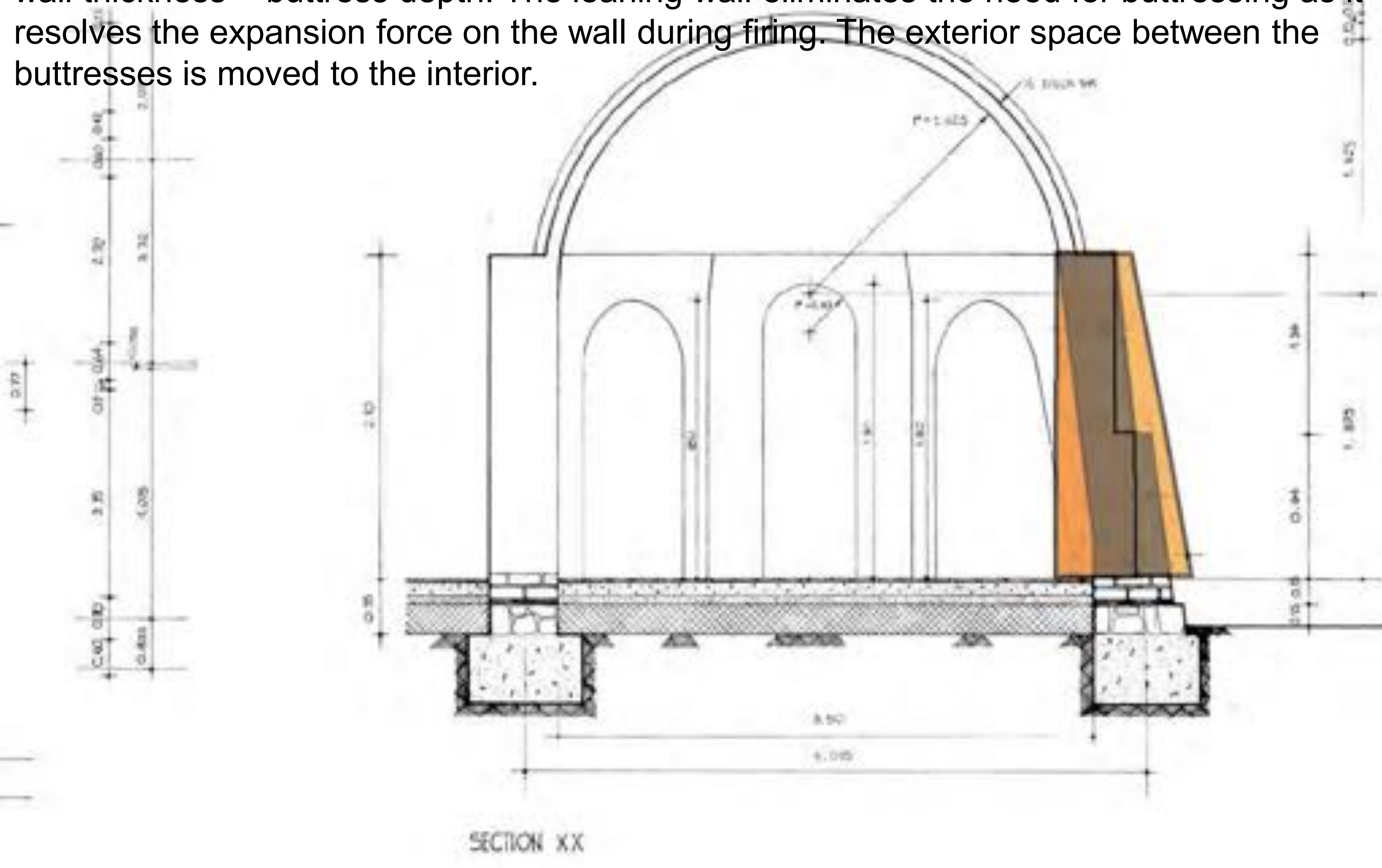
And as scaffolding.

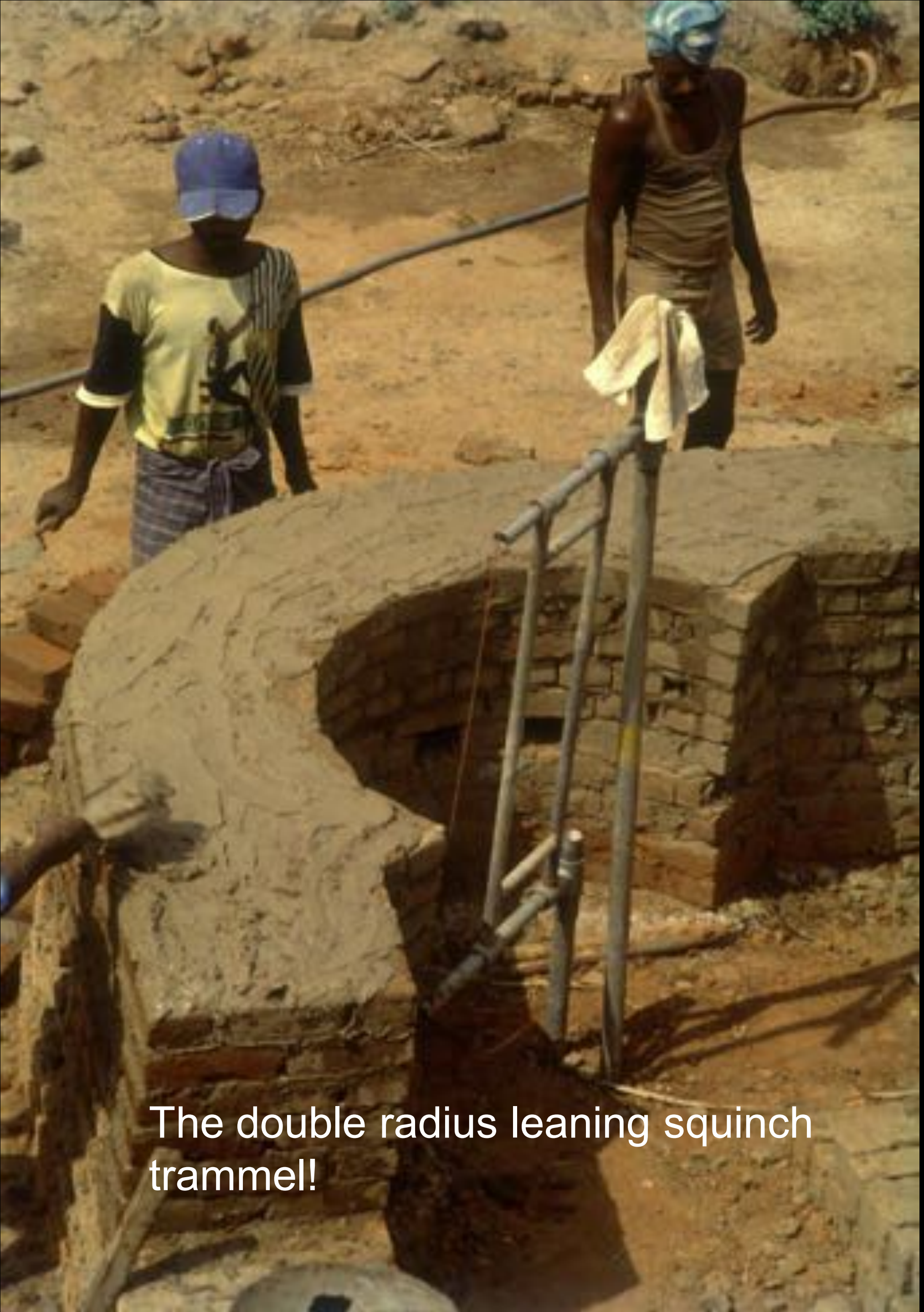
Beginning the 5 m dome. This is the first dome that this mason has ever built.

Note the saw-toothed edge of the upper dome layers. Each brick hangs on the previous course as well as on the adjacent brick from the same course.

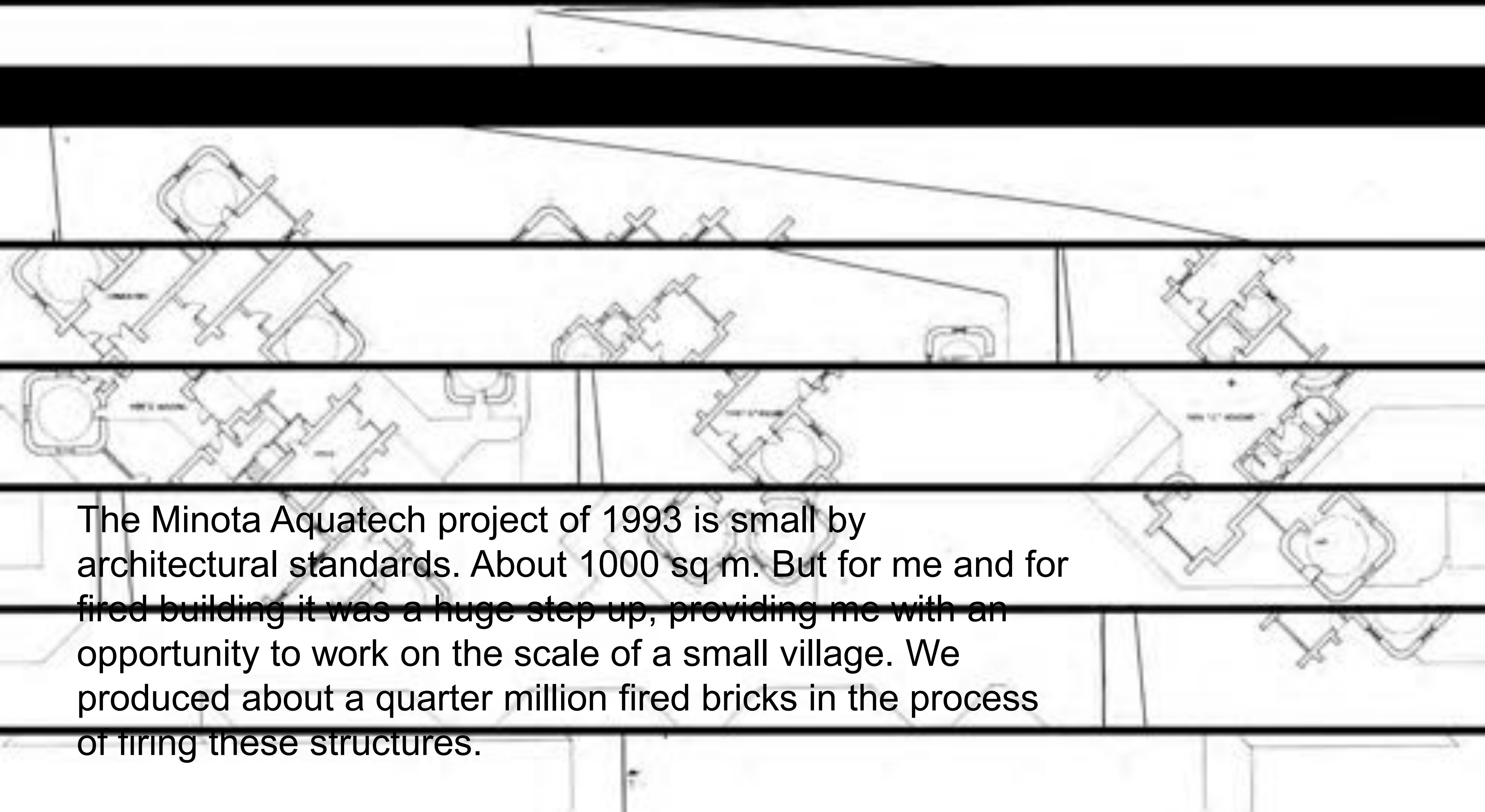
Agni Jata. The mud structure complete.

I began experimenting with leaning walls. The leaning wall (in grey) under this dome allows a 3 m dome to be placed on a 4 m squinched square floor plan. The orange is the wall thickness + buttress depth. The leaning wall eliminates the need for buttressing as it resolves the expansion force on the wall during firing. The exterior space between the buttresses is moved to the interior.

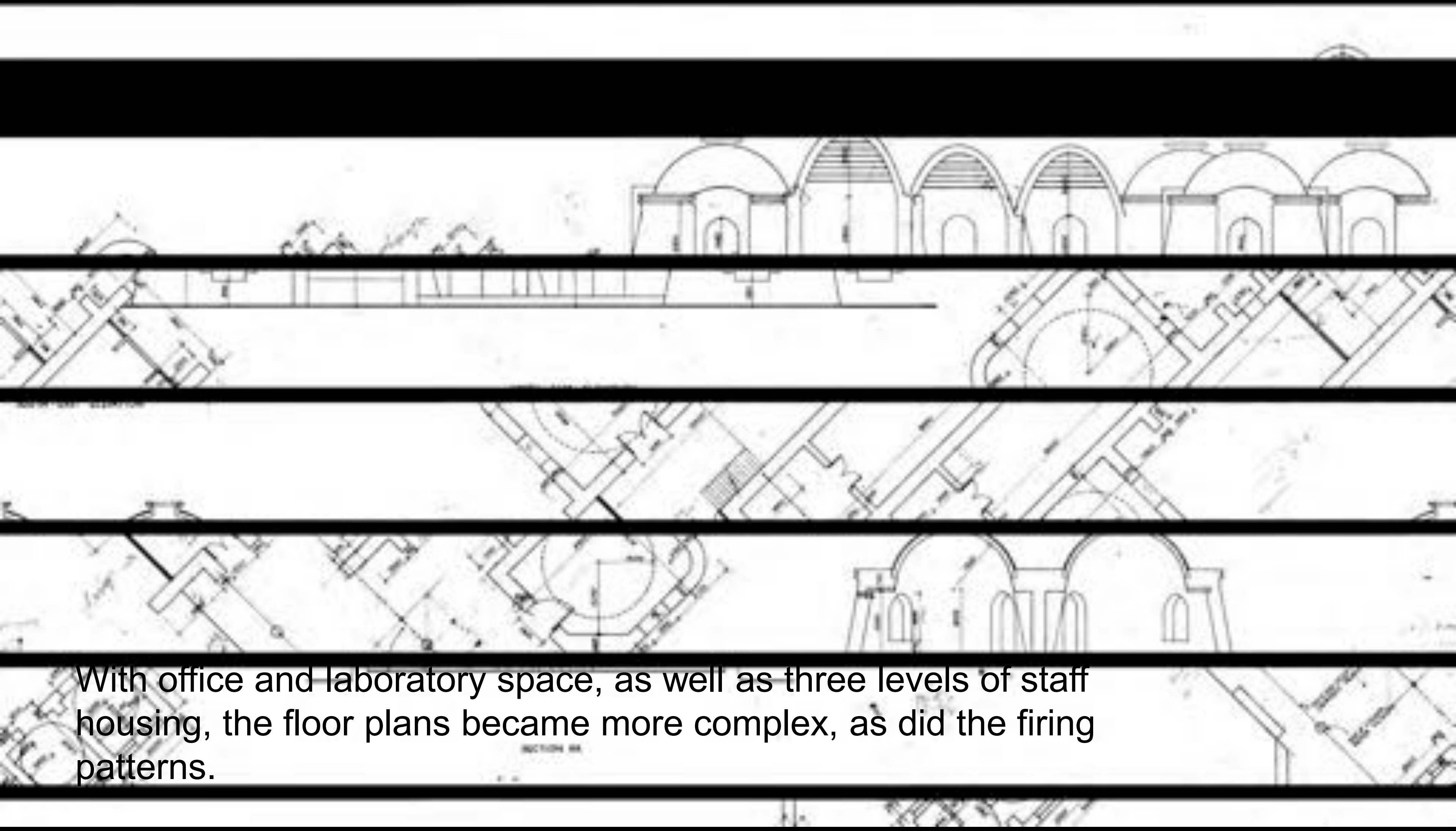




The double radius leaning squinch trammel!



The Minota Aquatech project of 1993 is small by architectural standards. About 1000 sq m. But for me and for fired building it was a huge step up, providing me with an opportunity to work on the scale of a small village. We produced about a quarter million fired bricks in the process of firing these structures.



With office and laboratory space, as well as three levels of staff housing, the floor plans became more complex, as did the firing patterns.

Mud  brickwork in progress. Tuticorin.

Product development.
Making high quality table-
molded brick.

Local scove kilns of between 50 and 100,000 bricks are fired in less than 24 hours. Brick quality is poor but adequate for filling r.c.c. column and beam structures. Buildings are invariably plastered with cement/sand mortar. Fair faced brickwork is rarely an option.

Firing team, local scove.

Table-molded floor tile.

Extruding tube sections

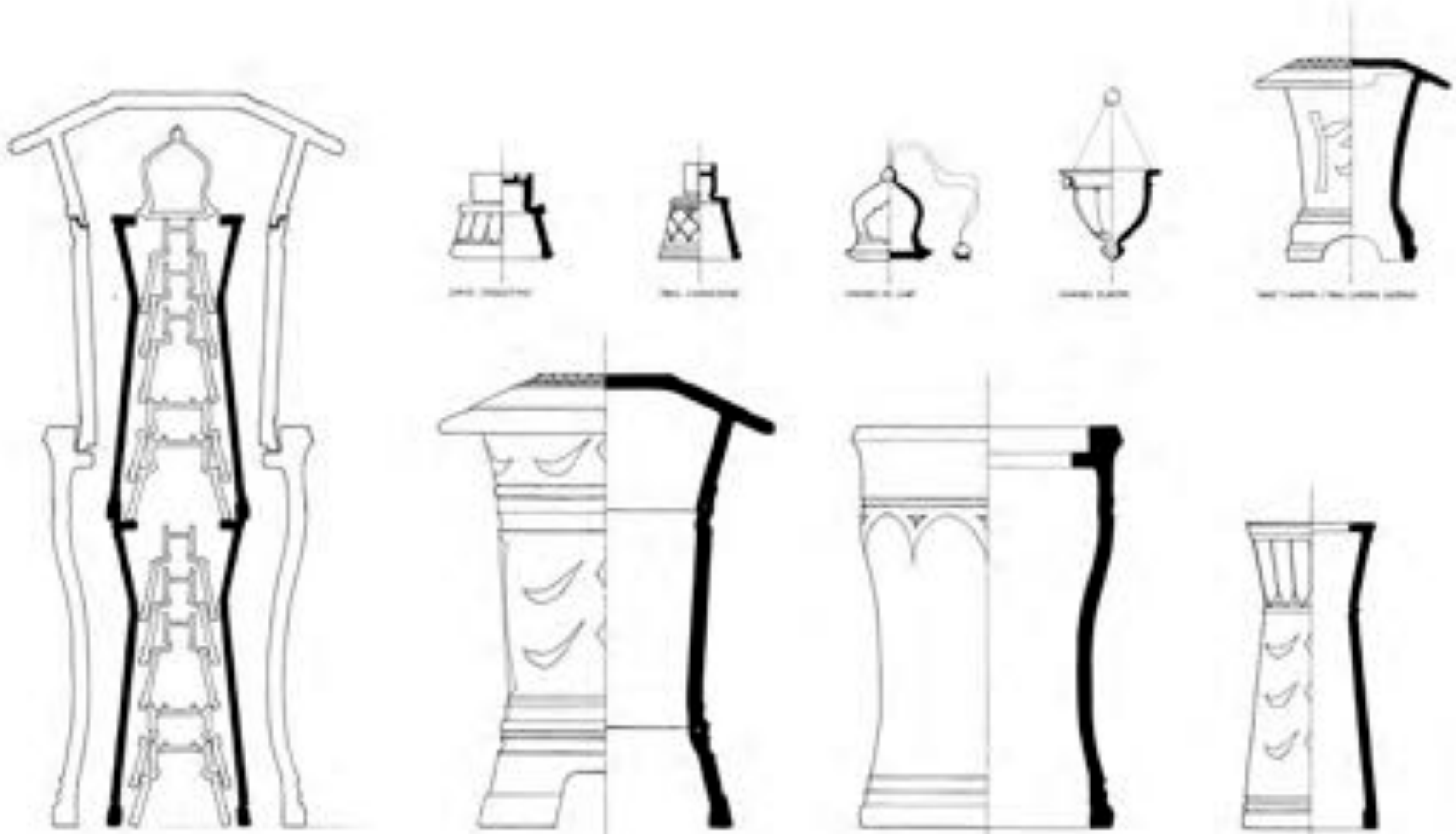
Working on a mold for a glazed earthenware toilet pan.

And a Nepalese master potter working on a hanging lamp. We collaborated with the Ceramic Promotion Project in Nepal, funded by GTZ.

Lamp base with stamped patterns.

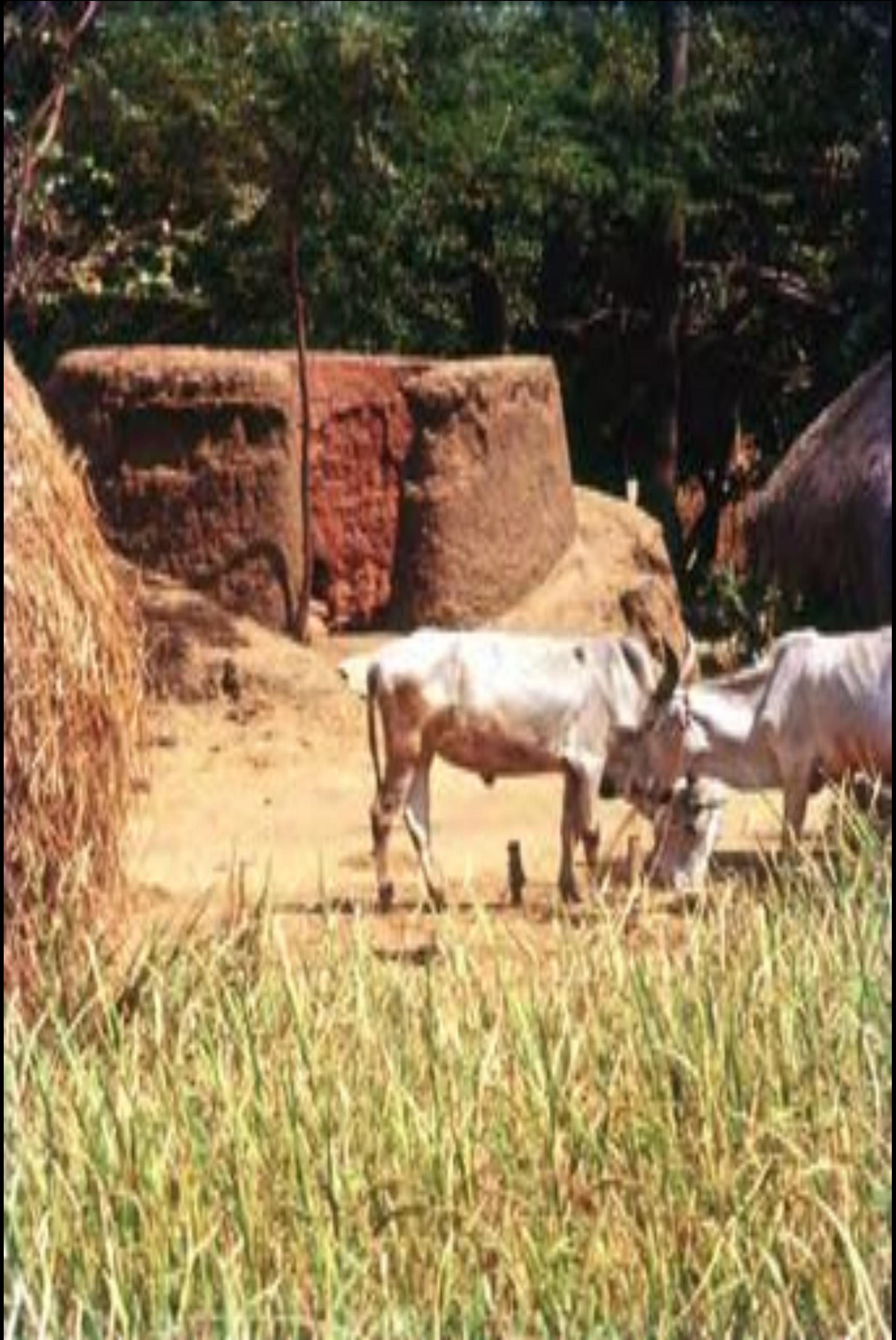
Most of the product load for a fired building is heavy clay ware. Bricks, tiles, window jallies, etc. This builds sufficient thermal mass to allow heat to penetrate as deeply into the walls as possible.

But in the top of the setting there is space for hollow ware. We designed a series of stools, lamps and hanging planters that stack economically to increase the value of the product load. Selling the product can cover the cost of firing—of stabilizing the sturcture.



These Aiyanar horses from Melkalpondi in Tamil Nadu, like the potters that make them, are an endangered species. At over 4 m tall they are among the largest monolithic fired clay sculptures anywhere.

In 1991 we toured South India with the Madras Craft Foundation looking for potters who still made large terracotta horses. We discovered twelve villages where a large horse could still be made in clay, though nearly all today are made in brick and cement.



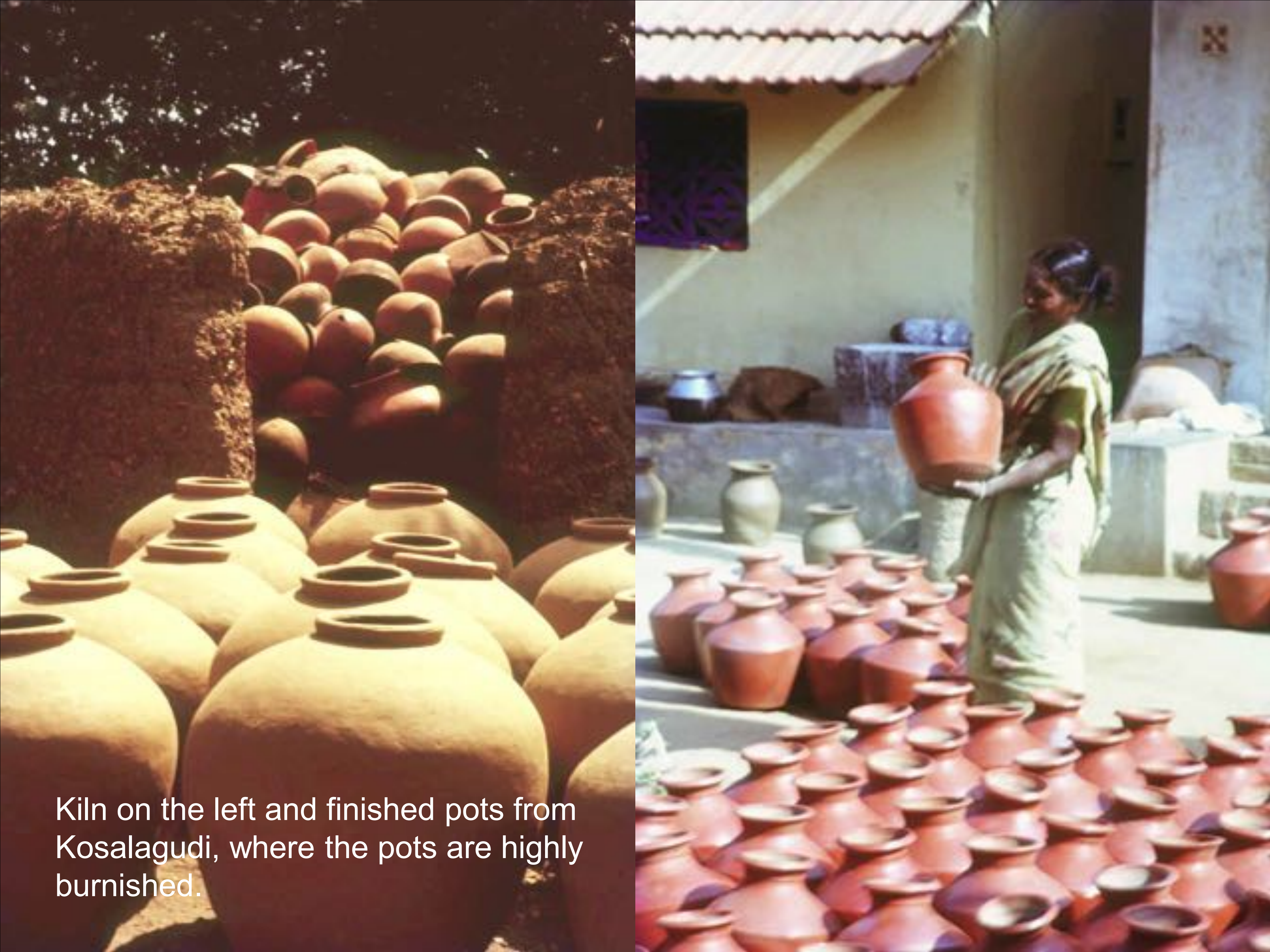
A kiln at Virianipetti.

Clay drying in the sun. Virianipetti.

A two person wheel.

Men throw thick-walled pots
with an open base.

Women paddle them into large thin-walled globes.



Kiln on the left and finished pots from Kosalagudi, where the pots are highly burnished.

A stunning avenue of terracotta horses at an Aiyanar shrine near Pudukottai in Tamil Nadu. There are literally hundreds of horses here. A horse is commissioned every year and brought to the shrine. The old horses are left in place and allowed to decay.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It is not all horses. The guardian figures in the background are 2.4 m tall.

We invited potters from the twelve villages to participate in a workshop in Chennai. We built a variety of kilns including the traditional village model on the right. The round kiln in the foreground was developed by Jim Danisch in Nepal and is designed to allow for preheating, something that village potters in India and Nepal generally do without.  Some of the villages we saw loose up to 35% of their work.

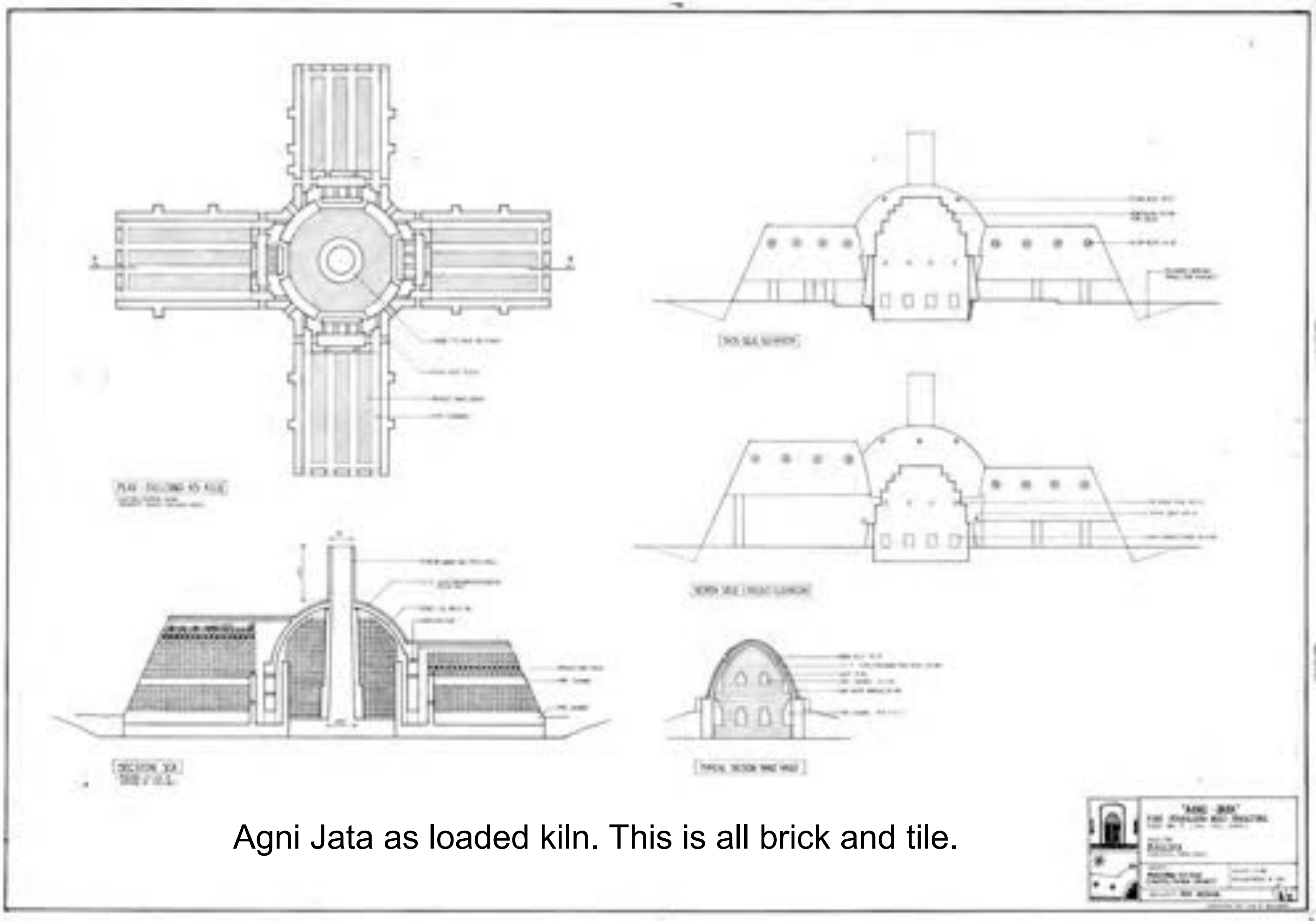
Manikkam adding a coil to a
large horse.


The piece is coiled and beaten into
walls of unbelievably thin cross-section.

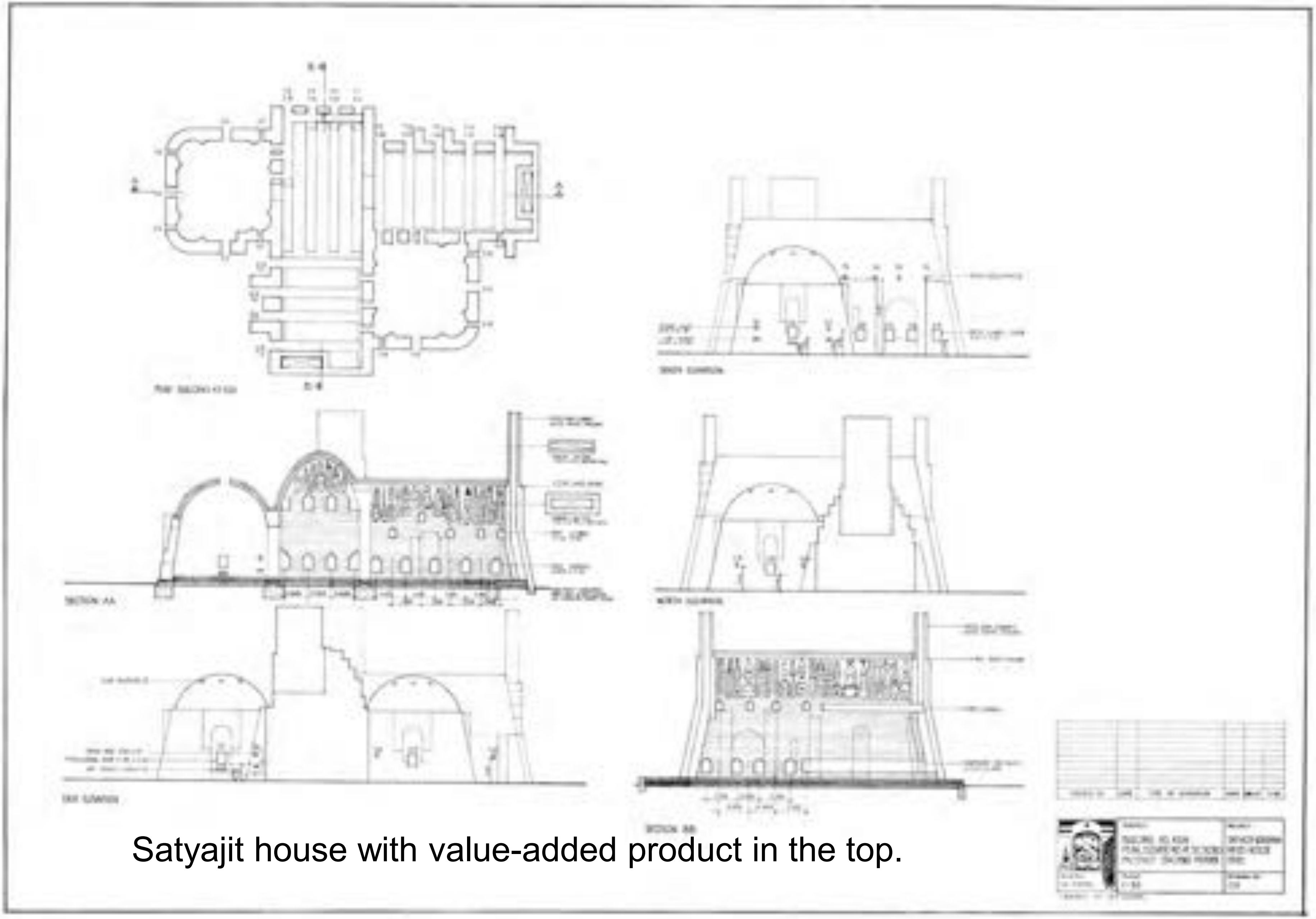

Making it possible to move these large pieces with four to six men.


Straw and a layer of mud cover the kiln. And the gods are acknowledged before the fire begins.

The fire is lit through a large fire mouth at the back. When the internal fuel that was placed inside the kiln with the ware ignites, stoking stops.



Agni Jata as loaded kiln. This is all brick and tile.



Satyajit house with value-added product in the top.

All the product for Agni Jata was made at our workshop in Pondicherry. 150 cartloads of brick and tile were transported 10 kms to Auroville.


Loading Agni Jata.

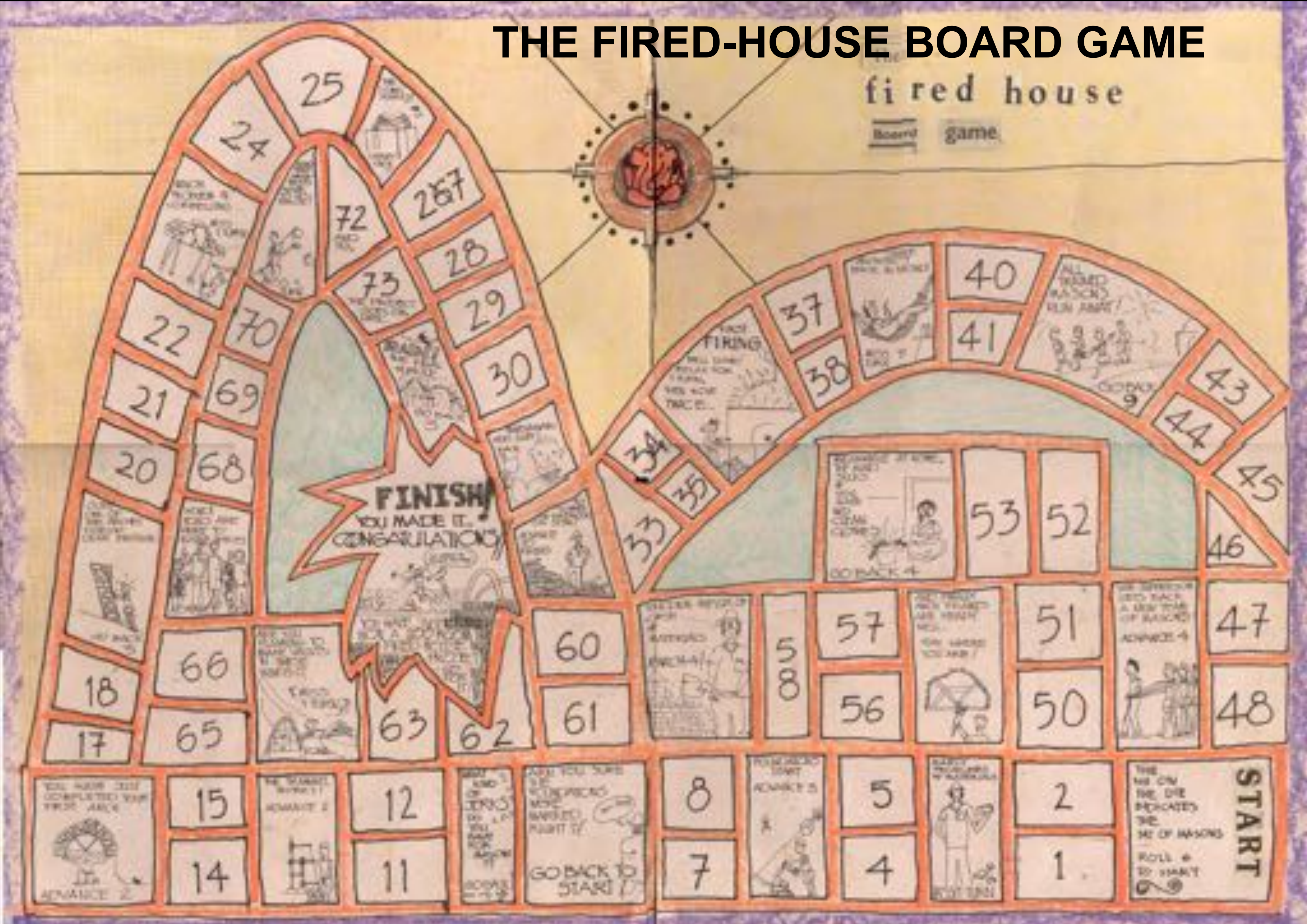
The downdraft chimney in the dome

Auroville Information Center. Smokeless stoves and lamps as part of product load. The smokeless stove was specifically designed for rural India. It is more fuel efficient than the standard village wood stove, and it takes the smoke out of the house, saving lungs and eyes.

Big rain in the dry season. It never rains in May... so they say. This is the result of  7 cms on one night in May, in spite of tarpaulin cover.

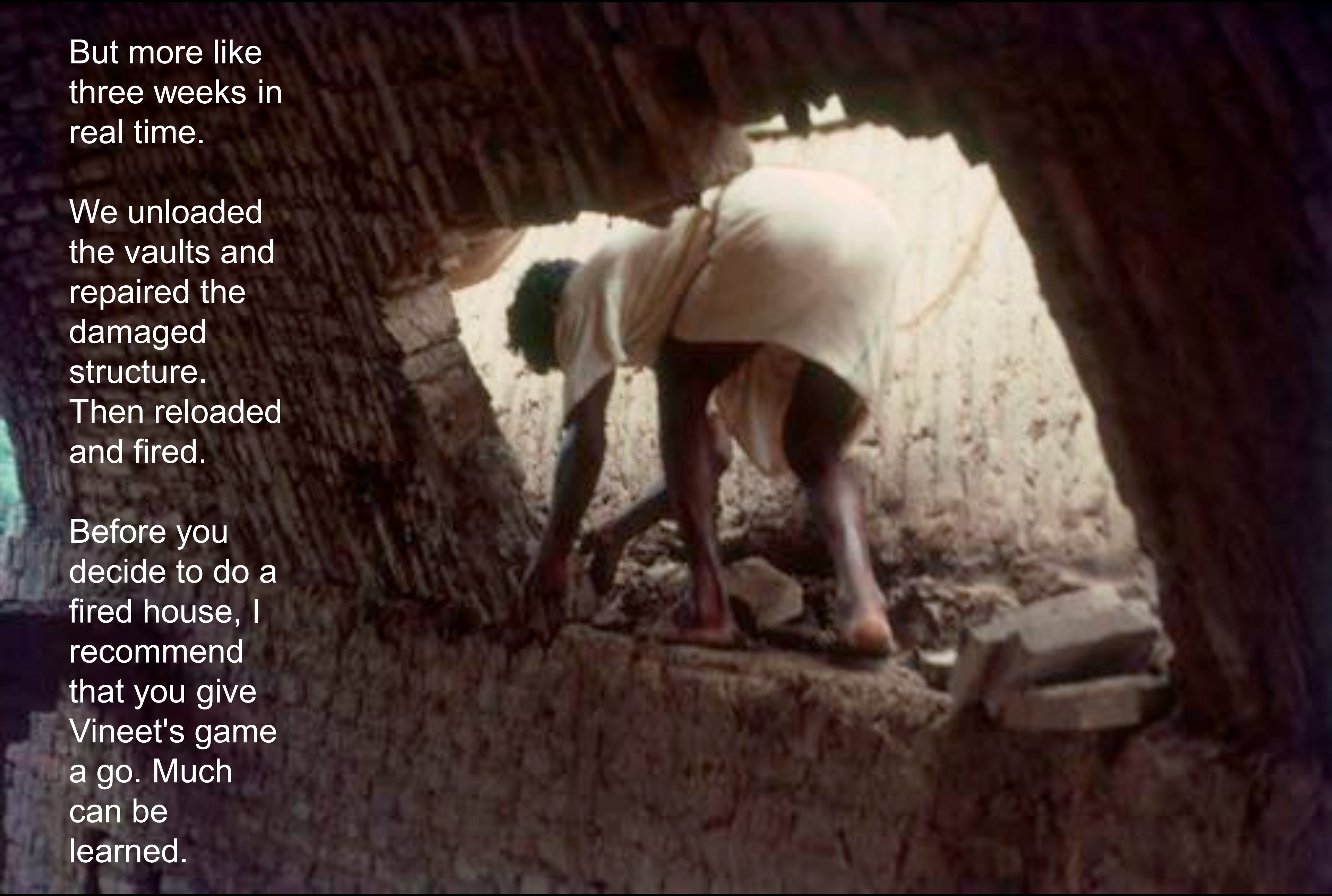
The structure had been finished and loaded with bricks. It was ready to fire.

# THE FIRED-HOUSE BOARD GAME




Rain. The final hurdle!

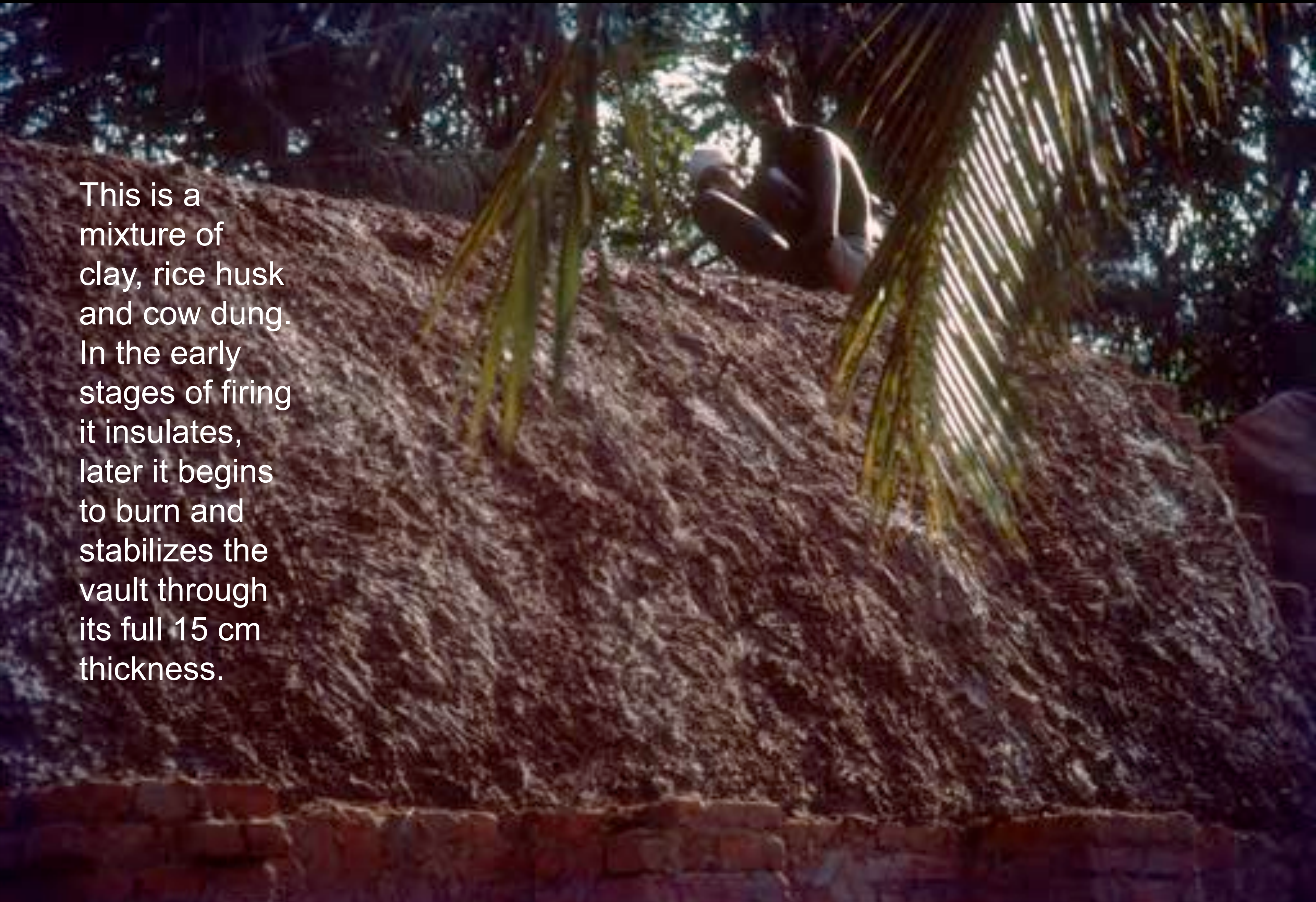
That will lose you three squares in Vineet Kacker's Fired House Board Game.



But more like three weeks in real time.

We unloaded the vaults and repaired the damaged structure. Then reloaded and fired.

Before you decide to do a fired house, I recommend that you give Vineet's game a go. Much can be learned.



This is a mixture of clay, rice husk and cow dung. In the early stages of firing it insulates, later it begins to burn and stabilizes the vault through its full 15 cm thickness.

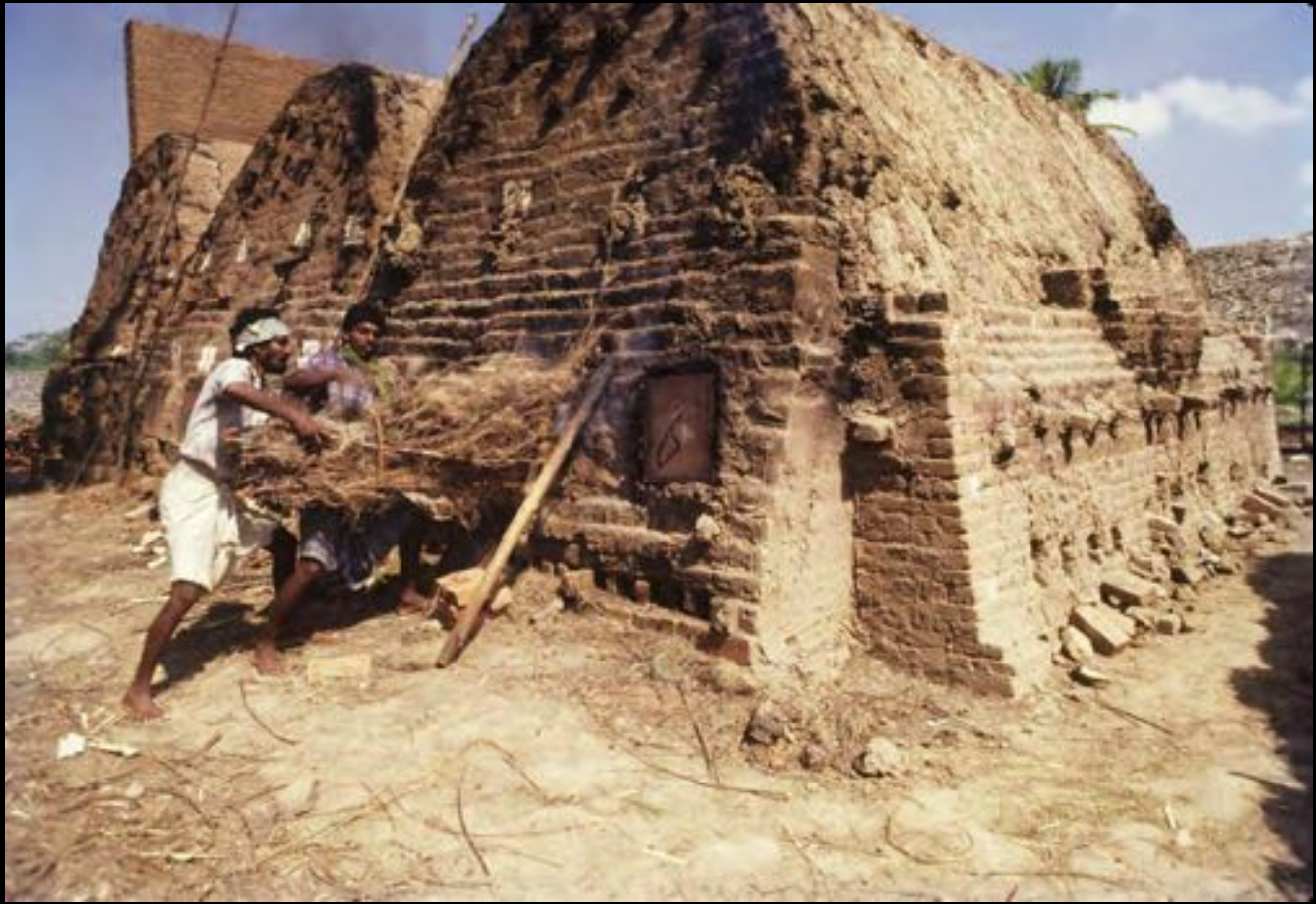
Fuel. I have used wood almost exclusively. Fuel efficiency was the Achilles heel of this process. When the energy audit is finally done, there is little difference in the energy consumed between this technique and standard techniques of house-building used in India.

The house cost may be somewhat less, but the inherent risks may outweigh the advantages.

Fuel stacked at Minota Aquatech,Tuticorin.

Here, in Tuticorin, Ganesh
as presiding deity.


The essential puja before the firing. Satyajit House.



Three connected vaults are fired cross-draft for fuel efficiency.

Pushing large bundles of casuarina tops deep into the firebox.

Fire burning in one dome. Chimney building at the end of another connected vault.

Night fire. Agni Jata.
Agni Jata was fired for four days.

Village house. Upplam.

I fired this house within 1.5 m of that coconut leaf roof on the right. At the peak temperature we were hosing the thatch down every hour.

Never again!

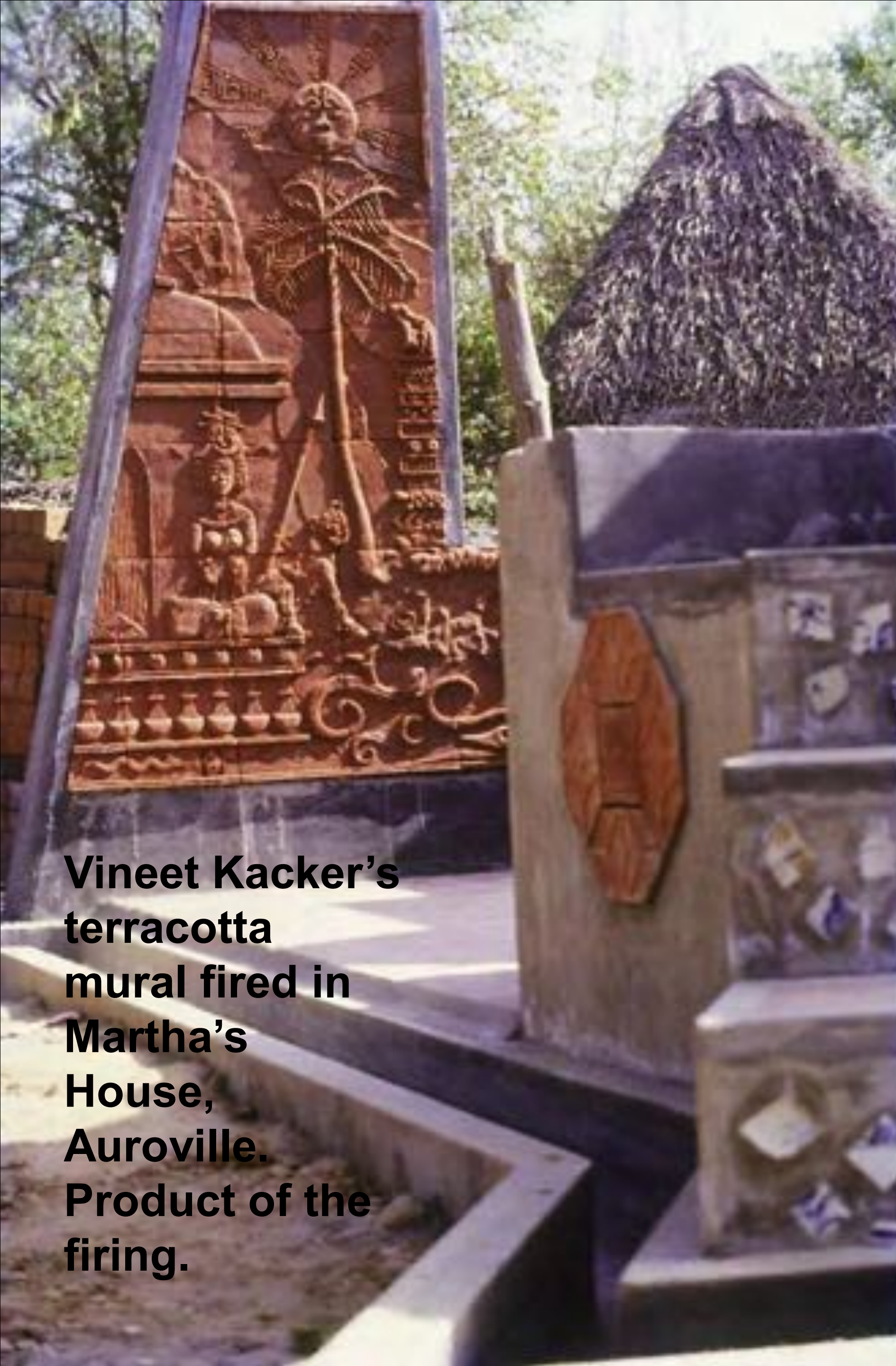
**Niches and candle stands. Value-added product.**

Unloading Agni Jata.
80,000 bricks.

After firing. Inside and outside of the fired structure.

Product brick going to a building site in
Pondicherry.


Bricks from Agni Jata used in this leather factory in
Pondicherry.

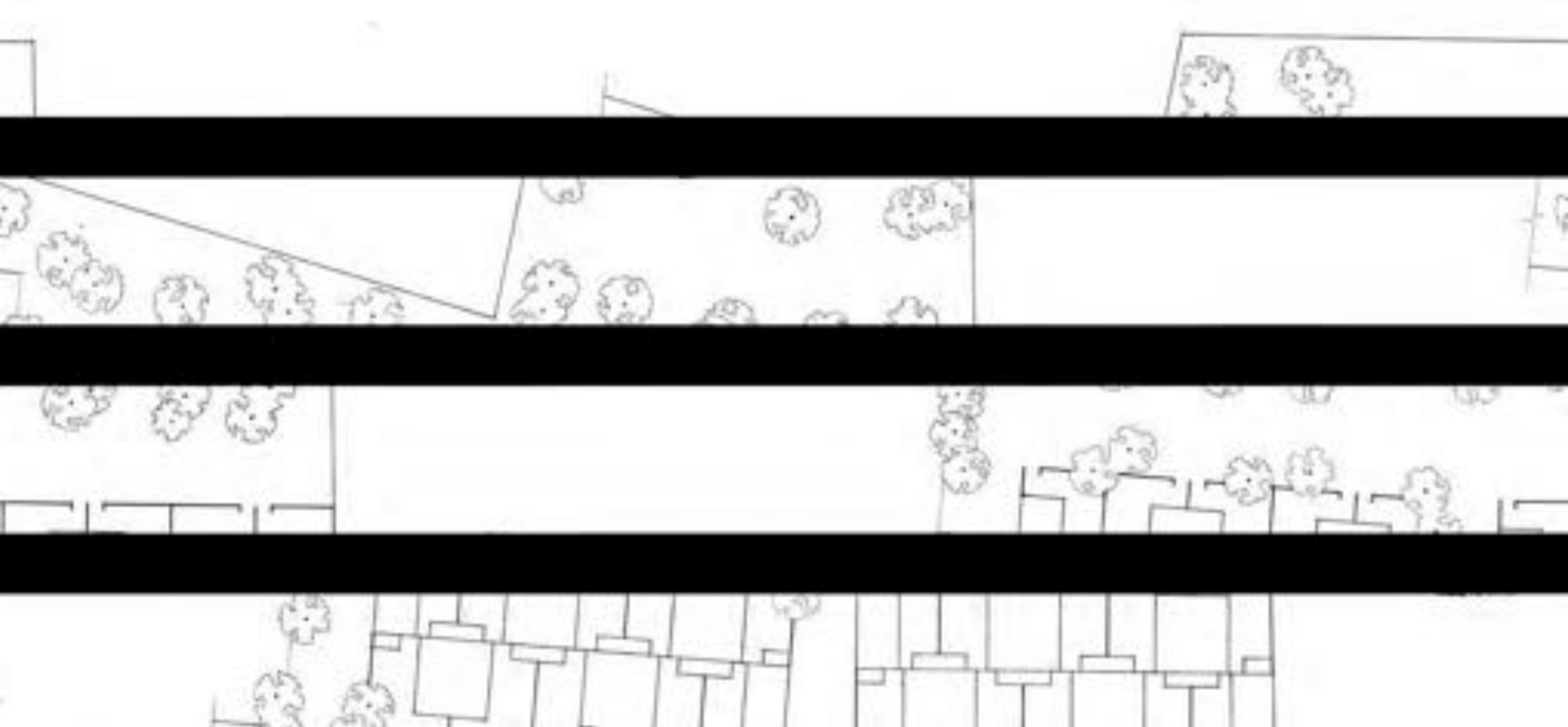



Vineet Kacker's terracotta mural fired in Martha's House, Auroville. Product of the firing.

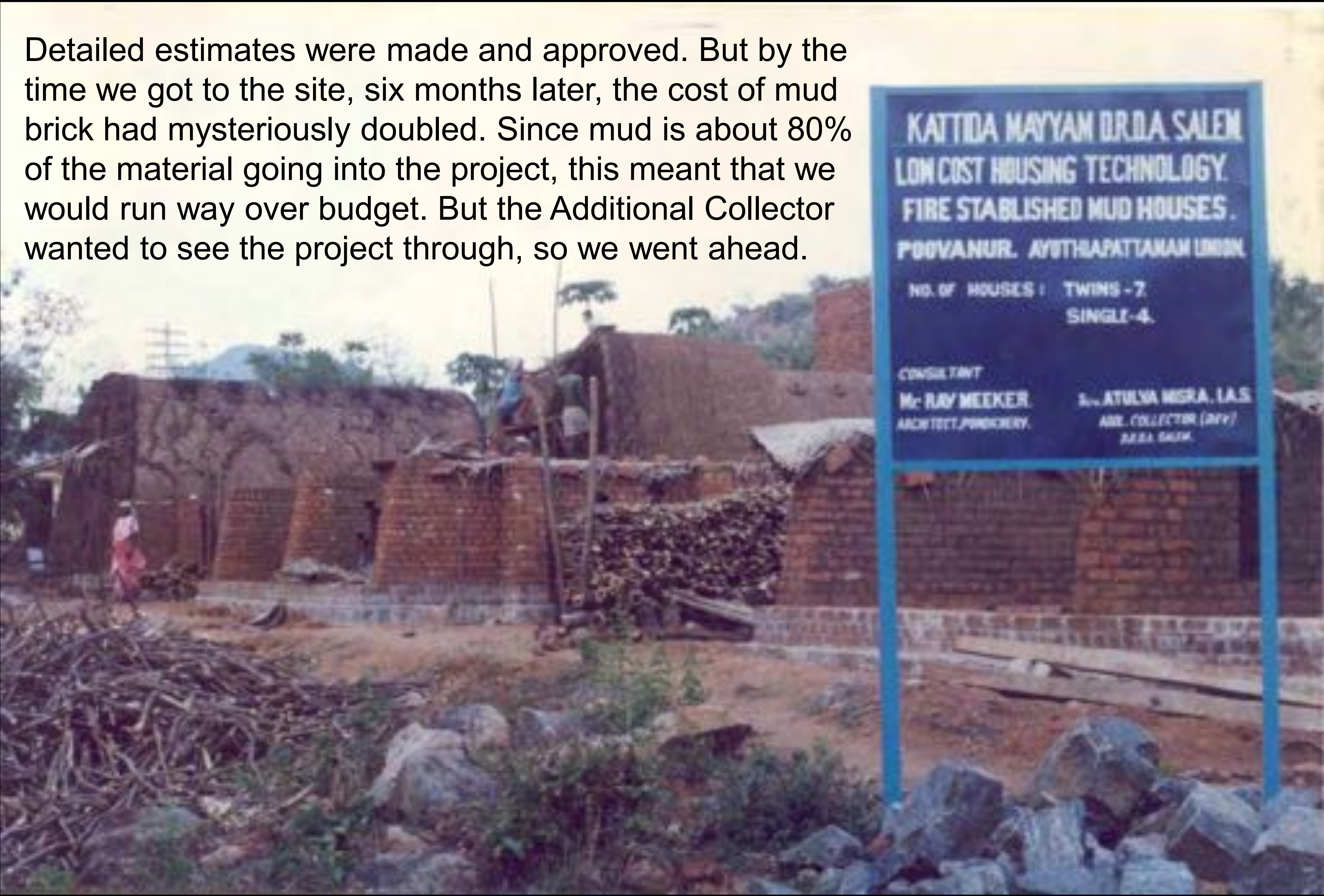
[redacted]

approached me in 1994.

[redacted]

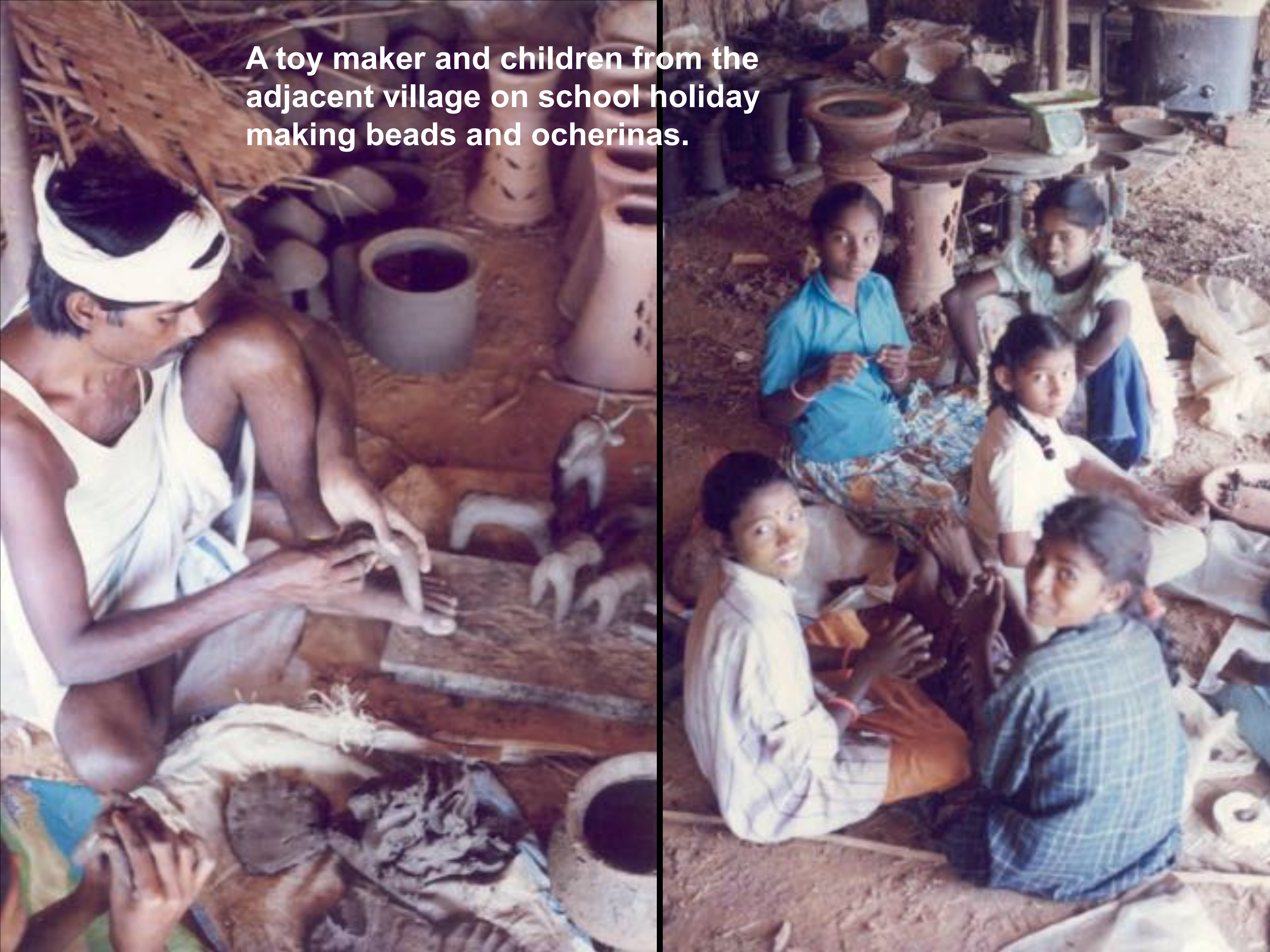


Detailed estimates were made and approved. But by the time we got to the site, six months later, the cost of mud brick had mysteriously doubled. Since mud is about 80% of the material going into the project, this meant that we would run way over budget. But the Additional Collector wanted to see the project through, so we went ahead.



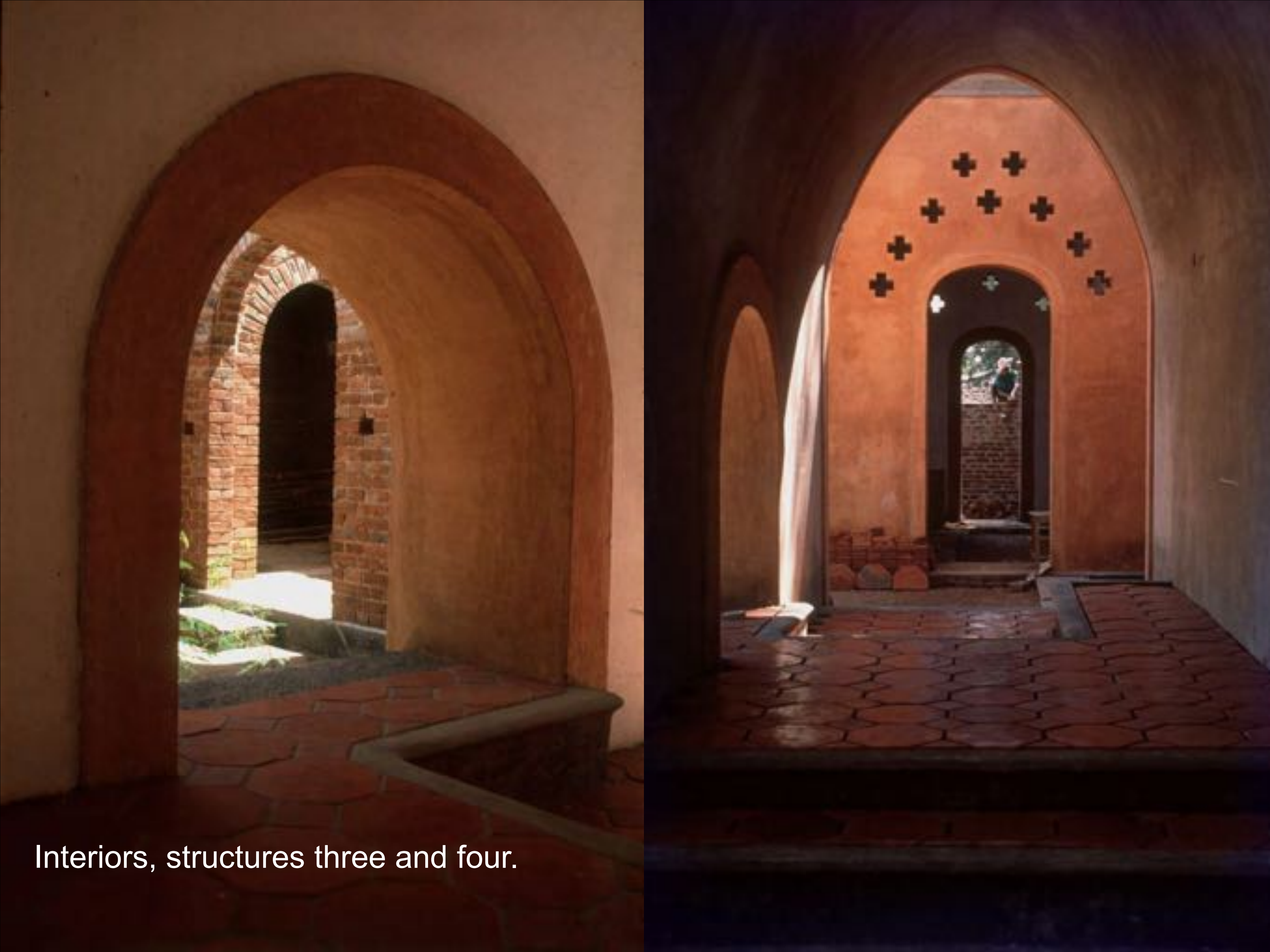
The Salem project had a lot going for it. An enthusiastic Additional Collector. A group of young engineers that were keen to try something this radical. In general it was assumed that transfer of technology would be difficult, if not impossible.

And we had a group of  ten village potters making everything from smokeless chulas to toys.


A toy maker and children from the adjacent village on school holiday making beads and ocherinas.

Three months into the project the Additional Collector was transferred and the Assistant Collector, who was soon to retire, took over. In the next three months the project slowly ground to a halt. Materials started disappearing. Funding stopped. Engineers went missing. We had built ten mud structures, fired six and finished only one. We did manage to prove that the technology was transferable. But  it was a sad ending for a project with so much potential.

Structures three and four, Golden Bridge Pottery compound.



Interiors, structures three and four.

Agni Jata. Auroville.

Agni Jata.

Agni Jata.

Agni Jata.

Satyajit House. Auroville.

Satyajit House

Cornice detail. Satyajit House.

Interior. Satyajit House.
The concrete loft is cast
after firing.


Martha House. Auroville.


Martha House.

Interior. Martha House.

Minota Aquatech. Tuticorin.

Minota Aquatech.

Minota Aquatech.

Minota Aquatech.


Minota Aquatech.

Volontariat farm. 1995. This project was given to a local contractor to realize. I helped with the loading and firing, and trained his masons in vault building, but everything else was up to the contractor.

My last fired structure was a small shrine for Nrityagram, a dance school outside of Bangalore. I received a cryptic message from Protima Gauri, the head of the school, “When are you coming to build the temple?"  She had a stone plinth for a temple that had never been built. This was 1997. I had returned to my studio the year before and  had just finished my first solo show of ceramic at the Eicher Gallery in New Delhi.

But the idea of a small shrine was intriguing. There was a brick maker about two kms from the temple site. That meant clay was good and I could order mud bricks ready-made. More significantly, these bricks were fired by adding coal dust mixed into the brick itself. I had tried this several years before with little success, but welcomed the opportunity to try it again. Fuel consumption had always been the most intractable problem in the process. This offered the possibility of reaching a fuel efficiency very close to the minimum.

Shrine at Nrityagram.

So with two young architects from Auroville, Anupama Kundoo and Dharmesh Jadeja as site supervisors, I began the experiment.

The tile work was all done in my Pondicherry studio and moved to the temple after firing. Protima Gauri was sadly killed in an avalanche on a pilgrimage to Lake Mansarovar in the Himalaya just before the completion of the shrine. This is a portrait of Protima, head shaved. The hand position is a mudra from the Odissi dance discipline. The bee taking honey from the lotus.


The base sphere of the spire.

The spire made from village pots.

Border pattern from
the Odissi sari.

Celebrating the finished shrine.

At Nrityagram, ironically my last test, we made a significant step towards solving the fuel consumption problem.

We used much less fuel and achieved a reasonable firing result. We sacrificed some control of the fire, but I am confident that control is possible.

And these experiments were in a very elemental sense, Common Ground.