THE FUTURE OF INDIGENOUS BUILDING MATERIALS

by Pliny Fisk

Pliny Fisk right, with conference participant Danny Buck.

Pliny Fisk runs an outfit in Austin, Texas called the Center for Maximum Potential Building Systems. In this paper he discusses native building materials in an exciting new light. He shows us that the potential for building our structures from locally available resources is far more extensive than most of us realize and that, rather than being primitive or backwards, such approaches can be far more sophisticated and appropriate than the "modern" techniques we now practice.

The method he outlines for mapping and utilizing local building materials can be applied to other resources as well. It can be used to chart a region's potential for self sufficiency in food, energy and other areas.

Too often at conferences that have to do with life support technologies, we are presented with massive amounts of data, lists of hard core experiences, or, if we are lucky, some historical perspective of how it all came to be. Rarely do we press one another for perspective or collectively direct our efforts toward a developmental continuum, and even more rarely do we admit to or even possess an overall methodology to track our work, to share it responsibly or even responsively.

If the future of indigenous building materials is to be properly addressed, we must deal with the subject on both a policy and technological level.

On the policy end, we have to realize that the benefits of miniaturizing or regionalizing our economy to produce jobs did not start and stop with the solar movement. In fact, the origin, destination and use of materials themselves is probably the first step not only of the creation of stabilized local economies, but also in the reduction of much of the environmental impact resulting from the by-products of manufacturing.

As to the technical level, we must admit to some standardized testing, especially for earth material building. We must understand the technical options and limitations of production equipment and be able to match these levels to the scale of need in a given region.

Although this presentation cannot possibly do justice to the number of factors needing attention in the realm of indigenous building, we will begin by offering a conceptual framework for the development of this emerging discipline. We will then survey some of the trends that are emerging in this exciting field.

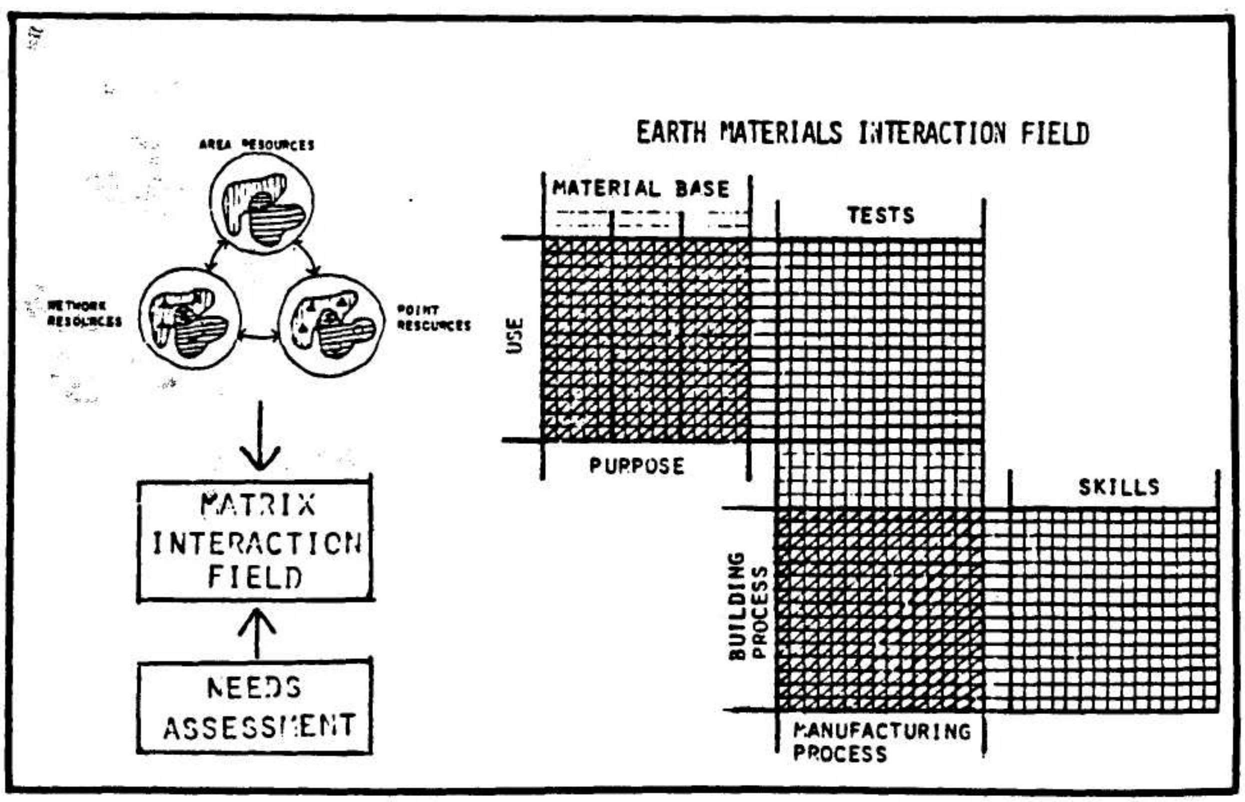
The mapping and analysis method described below is discussed largely as it applies to our efforts to identify appropriate native building materials for the state of Texas. Readers should keep in mind that this method can be applied in any region and to many resources in addition to building materials e.g. food and energy.

METHOD

This paper presents indigenous building materials in the context of an overall environmental approach. The approach is partially based on mapping as a medium of information exchange. Mapping is the tool whereby plant taxonomists record species, geologists record minerals, and soil scientists record soil data. Mapping is a statistical base for identifying areas of poverty, jobs, skills, manufacturing, retail, etc. It is generally the basis from which physical land use plans are made, and environmental impact statements presented. But, most importantly, mapping allows us to cross disciplinary boundaries and look at all of the above at the same time in one comprehensive picture.

As a tool for identifying the indigenous building materials and techniques best suited to a region, mapping tells us not only where a resource is, what area it covers, and its general quantity, but can also tell us whether a local extractor, fabricator or mason exists. If many indigenous materials are mapped, the user can know how many different building components can be derived from a given locale, who has used them and in what combination(s). As a networking tool, depending on the information recorded, mapping can help someone gain access to someone else's experience in a similar region with a similar set of resources.

In our mapping we identify three basic kinds of resources. Area resources are the actual physical resources such as forest and soil types, quantities and locations. Point resources are the special human skills and knowledge related to the area resources being mapped. For example, who and where are



the people in an area experienced in working with, a particular indigenous building material. Network resources pertain to the economic and social infastructure of the region as it relates to the subject under study. Network resource maps look at the scale and type of trade (e.g. monetary, barter, reciprocity, capital intensive etc.) taking place in the region and the availability of related goods, services and information. These three levels of resource identification--area, point and network--allow us to assess the needs of a region and offer possible local solutions.

The needs assessment determines what resources must be developed first and in what areas of life support, e.g. food, fuel, shelter. It also cross-relates their importance to both population and environment. In order to understand the various relationships just described, we use an interaction field matrix which compares issues identified in a needs assessment with a region's three resource areas. If, for example, a need is established and the area resources to fulfill that need are identified but the local population knows little about them, some amount of training is required in the area of testing, fabrication and/or skill development.

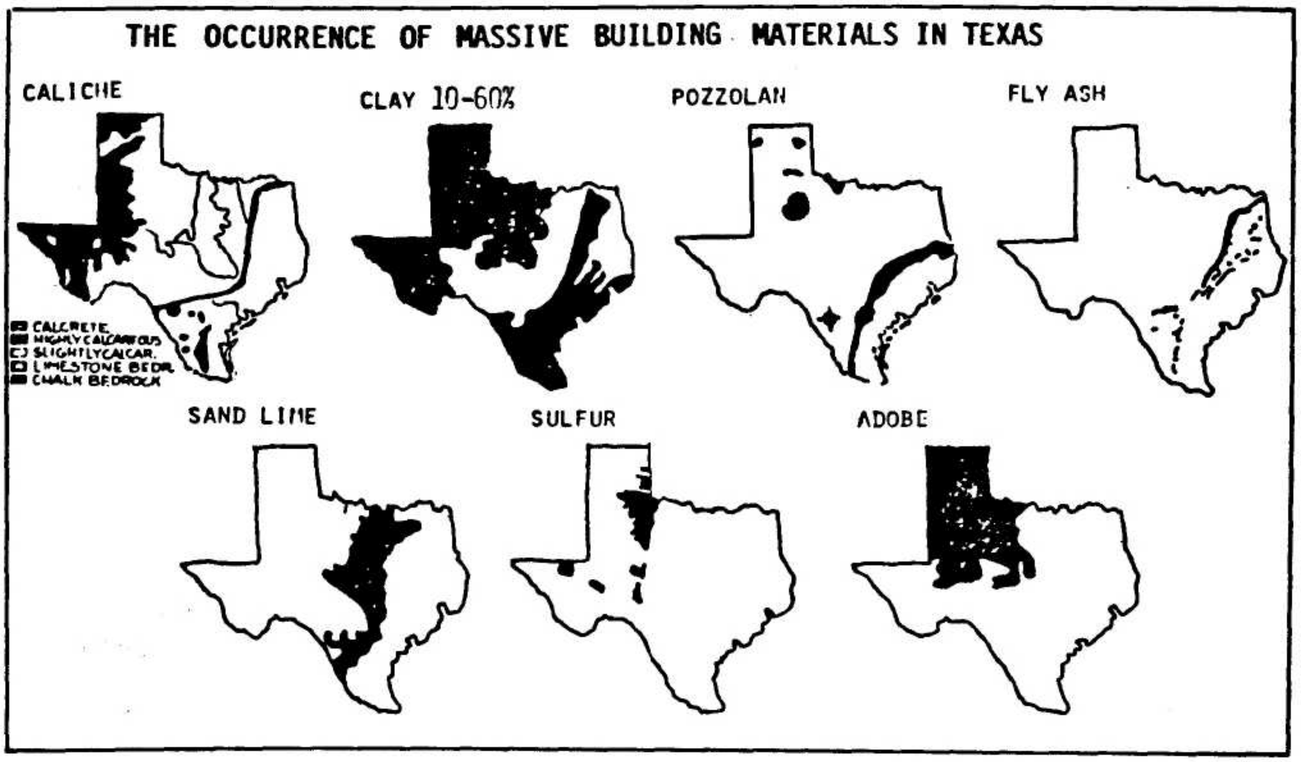
There is not room here to fully describe the cross-referencing process we use. The earthen building materials interaction field illustrated above gives the reader an idea of the variables that should be considered when choosing or developing a technology for a specific region. Let's now take a look at some of the specific approaches we've taken with indigenous building materials in Texas.

THE OCCURRENCE OF MASSIVE BUILDING MATERIALS IN TEXAS

(1) Caliche is a high calcium carbonate soil characteristic of lower soil horizons in arid, semi-arid environments. It is estimated that these soils comprise 14% of the earth's surface, and over one-third of Texas' land mass.

Caliche can be fabricated into very strong building blocks. The mix for caliche block depends on the calcium carbonate content. With a good caliche, a mix of eight parts sand, nine parts caliche and one part cement is adequate. The cement is used as a stabilizer, but even it can be replaced with a locally available mixture of pozzolan and lime.

Caliche block production facility started by the Center for Maximum Potential Building Systems. (CMPBS)



(2) Stabilizable Earth ranges from 20% to 55% clay and can be stabilized chemically or by pressure. Earth with this range of clay content comprises about 60% of the Texas land area.

(3) Pozzolan is a fine grain, amorphous silica which, when mixed with lime, is called Roman cement. A typical pozzolan mixture is 5% lime, 25% pozzolan, and 70% sand/gravel aggregate. Pozzolan is 1400 feet thick in Mission, Texas, and decreases to 2 feet thick north of Houston. Pozzolan was the principal cementaceous material used to build the Roman Empire.

(4) Flyash is similar to pozzolan but is not really an earth material since it is derived as a waste from coal burning plants. However, if Texas energy policies continue as per present plans, we will literally be knee deep in the stuff in no time. The material has been used to make brick.

(5) Sand Lime is an autoclaved pressure molded mixture of sand, lime and water: 8% to 12% lime, 88% to 92% sand and 3% to 5% water.

(6) Sulfur is a subsurface mineral of which Texas possesses a reported one-fifth of the world's supply. Sulfur is mined by drilling, and presumably could be utilized from the well on-site in sprayed form, foamed form and as building block. Sulfur block is made by combining 65% to 70% sand and 30% to 35% sulfur. Several different fireproofing methods for sulfur are available at relatively low costs.

Gypsum is not specifically mapped but usually occurs in parallel geologic formations to sulfur. It is first calcinated over fire and then ground and mixed with water (Plaster of Paris).

(7) Adobe is a sandy clay soil containing virtually no organic matter. It is characteristic of arid and semi-arid climates. At its best, adobe contains about 20% clay and 80% sand, but a wide variety of mixes are used with the resulting need for higher stabilizing requirements as one departs from this ratio. Adobe makes up approximately one-third of Texas' land surface.

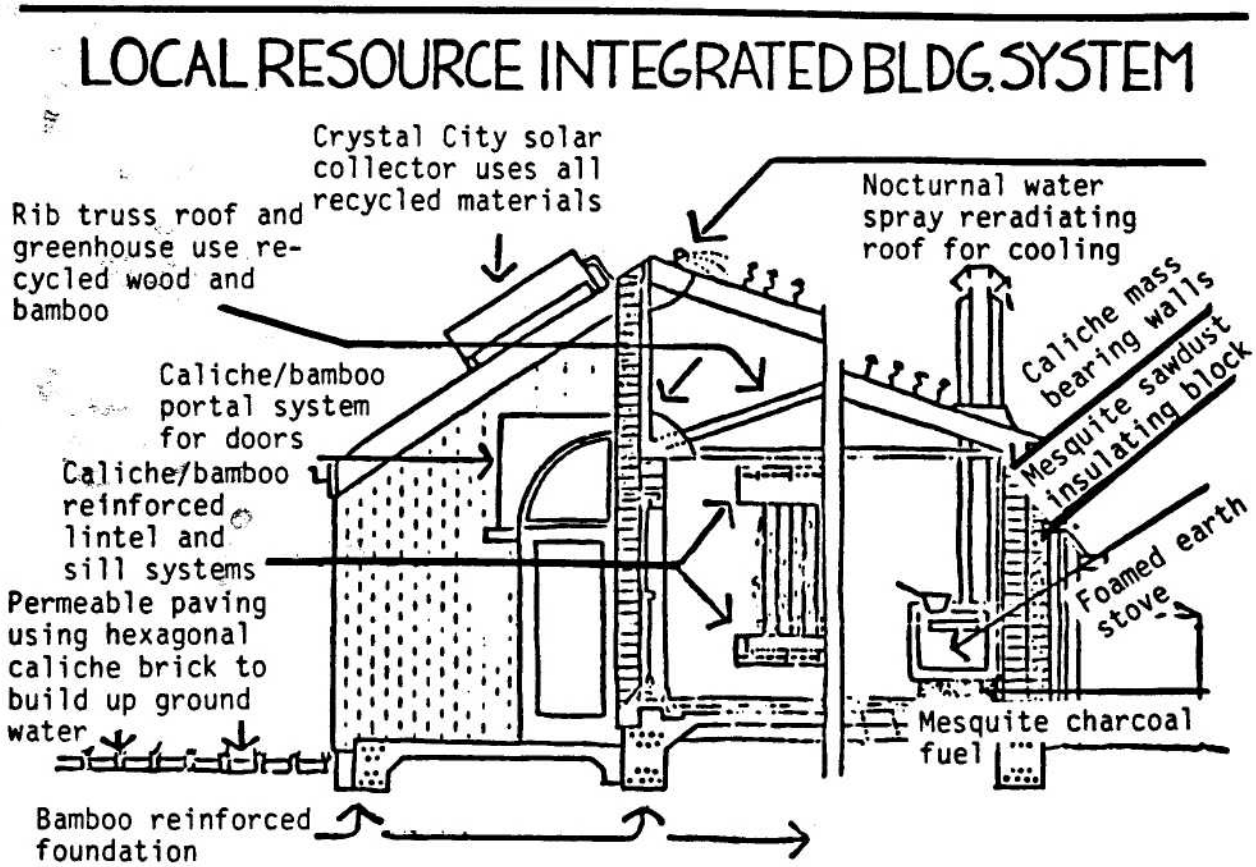
Insulating block made from sawdust.

CASE STUDY

Now let us examine the design and construction of a real building. Myriad materials and material combinations are required. If one were to study the headings and subheadings categorized in our interaction field cited earlier, one would realize the range of questions needing to be asked. Remember, the main purpose of this building we are about to describe is to develop the use of a wide variety of local resources and to show what impact this approach would have on local energy consumption and job production.

The building diagrammed below describes in cross section some of these material systems. Drawings that follow describe such material combinations as well as utilities in more detail, and key these components into spatial maps. Let us start with the building shell.

The building shell, which is now complete and located in Carrizo



Springs, Texas, contains six regional systems. They include a trickle-type re-radiating roof, bamboo for reinforcing of foundation and for door and window lintels, caliche for use as mass and structural building block, and mesquite hardwood for parquet-type tile floors, and as a sawdust-base for exterior insulating block.

The trickle-type reradiating roof, is coupled to pipes in the heat absorbing foundation slab. The performance of the roof depends on the ability of white-painted corrugated roof metal to re-radiate heat and evaporate the water trickling over it at night. This water is then cycled through pipes in the slab foundation. The performance also depends on how many BTU per square foot of roof area the night sky is able to absorb. In the area of Carrizo Springs, this roof is able to lose approximately 100 BTU per square foot which is approximately equivalent to the daytime heat gain per square foot of floor area of a well insulated building in this region.

Bamboo, which requires a lot of water, can be grown only along the banks of rivers in our demonstration area. The bamboo must be cut as close as possible to its dormant season in order to reduce the amount of water in its stems. Bamboo is capable of withstanding 18 thousand pounds per square inch in tension. It is stabilized with asphalt emulsion and then used in place of rebar as reinforcing material in cement or calcrete (caliche/concrete or caliche/pozzolan) block. No stems beyond 3/4" diameter are used. When the bamboo is greater than 3/4", the bamboo reed is split.

Mesquite is a hardwood that grows prolifically in this border region. Our group has organized community wide gathering of mesquite to be used in six low income rural towns in South Texas. At 13,200 BTU per pound, mesquite makes about the

Bamboo used as reinforcing bar in a foundation.

best charcoal in the U.S. It is an extremely hard wood, comparable to mahogany. We have incorporated mesquite into this building in two ways: 1) as a floor tile and 2) as a material base for insulating sawdust block. Sawdust is a highly available waste material in the region. The tiles are made by using the rough cutting capability of a local mesquite sawmill and a bandsaw that slices 6" x 6" x 2-1/2" pieces into 1/2" tile. The completed sawdust blocks weigh about one-third less than caliche block, which weighs about 20 pounds per 8" x 10" x 3-1/2" block.

Cedar does not grow in our study area and must be imported from a neighboring bioregion. The cedar is required because the. local mesquite tree rarely grows straight and does not produce good lumber, whereas cedar is the material in closest proximity which can be used to fulfill structural uses. It also is favored since it is rot resistant.

INSULATING MATERIALS WHICH OCCUR NATURALLY IN TEXAS

(A) Mesquite, Pine: Mesquite and Pine are both usable in insulating block when mixed with cement and a base material such as sand. Mesquite sawdust must first be neutralized by soaking it in an alkaline solution of lime water, and then mixed in a solution of one part cement to eight parts stabilized sawdust. Pine sawdust can be mixed dry in proportions of six sand, two Portland, two lime, eight sawdust. Both blocks must be protected from the weather with latex paint. These sawdust insulating bricks are fireproof but have not been subjected to long term weathering effects as far as we know.

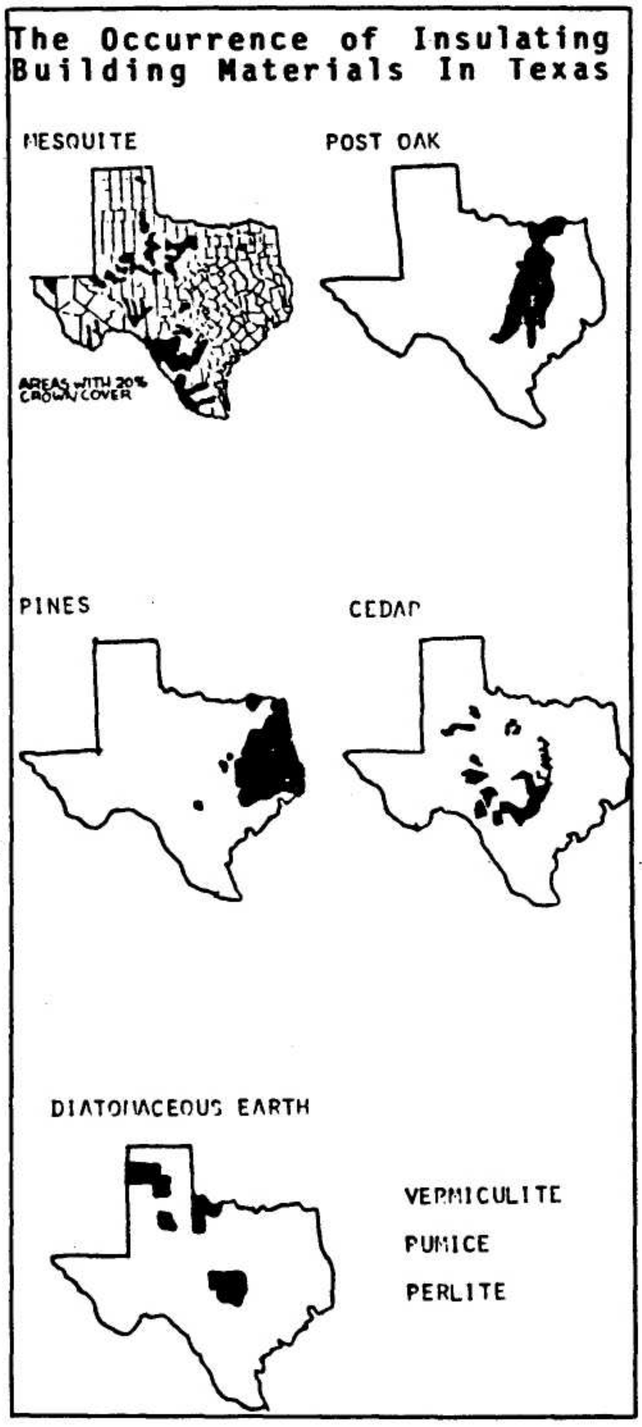
(B) Oak and Cedar sawdust or chips can be soaked in Boric Acid for fire-proofing and then used as insulative fill in hollow walls.

(C) Diatomaceous Earth is the deposit of silicious fossils whose dry weight is 10 to 28 pounds per cubic foot. It is mixed with three parts sawdust, three parts shavings, one-part cement, one part diatomite and one part clay. It can be used in the form of poured walls or blocks.

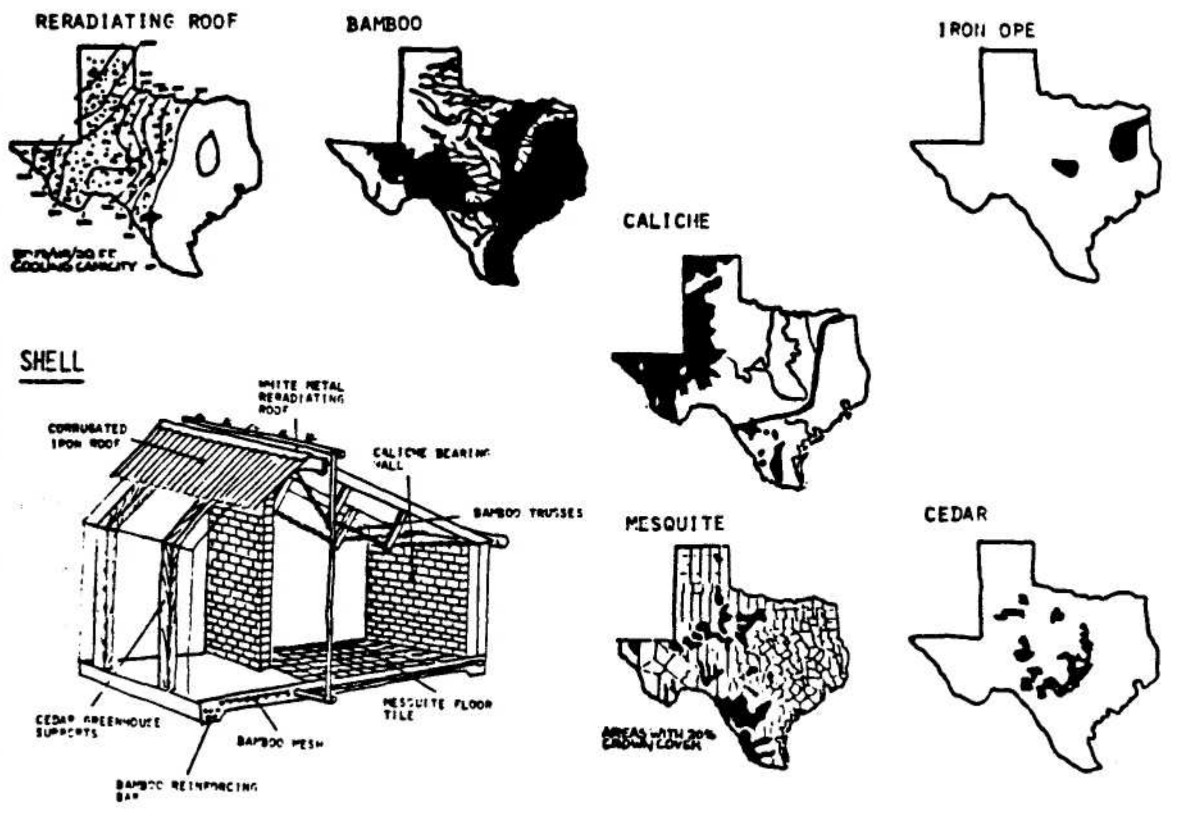
(D) Vermiculite is a micaceous mineral which expands upon exposure to heat of about 300 degrees C. It can be used directly as an infill insulation.

(E) Pumice is a lightweight, porous volcanic aggregate which can be mixed with cement.

One important measure of the usefulness of a massive indigenous material is the amount of heat it can store when used in solar buildings. Another factor to consider is the amount of energy required to manufacture and transport a building material to a building site. While the energy consumed for transportation of adobe, caliche, sand lime, gypsum, diatomaceous earth and cement are about equal the energy used in the manufacture and application of these materials varies widely. We are working on a chart which lists these characteristics as well as the structural and thermal qualities of materials. As conventional energy costs soar, these kinds of considerations will become increasingly important.

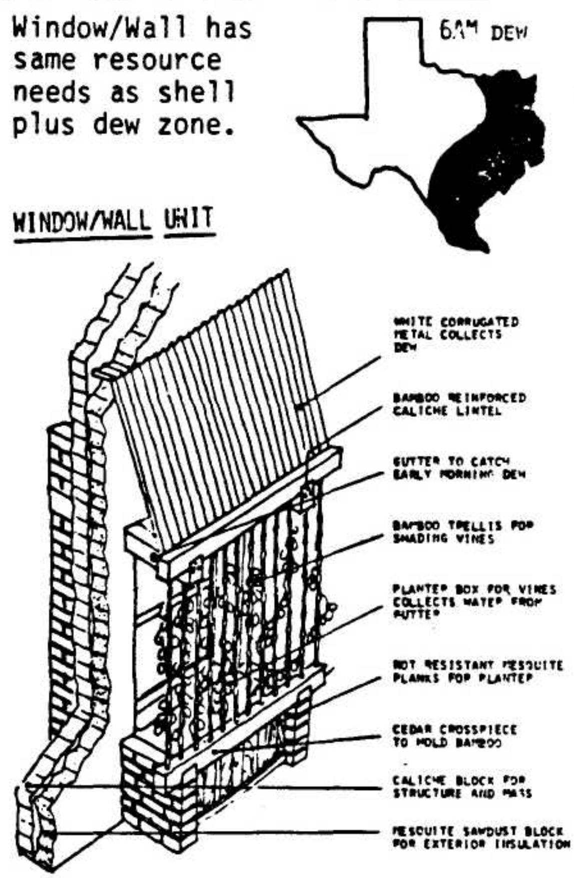


Areas Of Texas Where Materials Used In The Building Shell Occur



Iron ore is another material which must be imported, in the form of corrugated tin roofing. It is required for the night sky cooling roof system. When painted with high emmisivity white acrylic or lime based paints it is far better at releasing heat to the night sky than any locally available material.

Our window/wall unit uses resources similar to the building shell. The on1y major difference is our dew catchment technique which automatically waters vines that are used to shade east and west facing windows. This technology works only in coastal and near-coastal regions where water vapor is high enough in the early morning hours to collect as condensation on surfaces that can cool to the night sky. The planter box is made of mesquite because of its resistance to rot. Bamboo is used as reinforcing but this time in cantilever lintels and as a trellis for the vines.



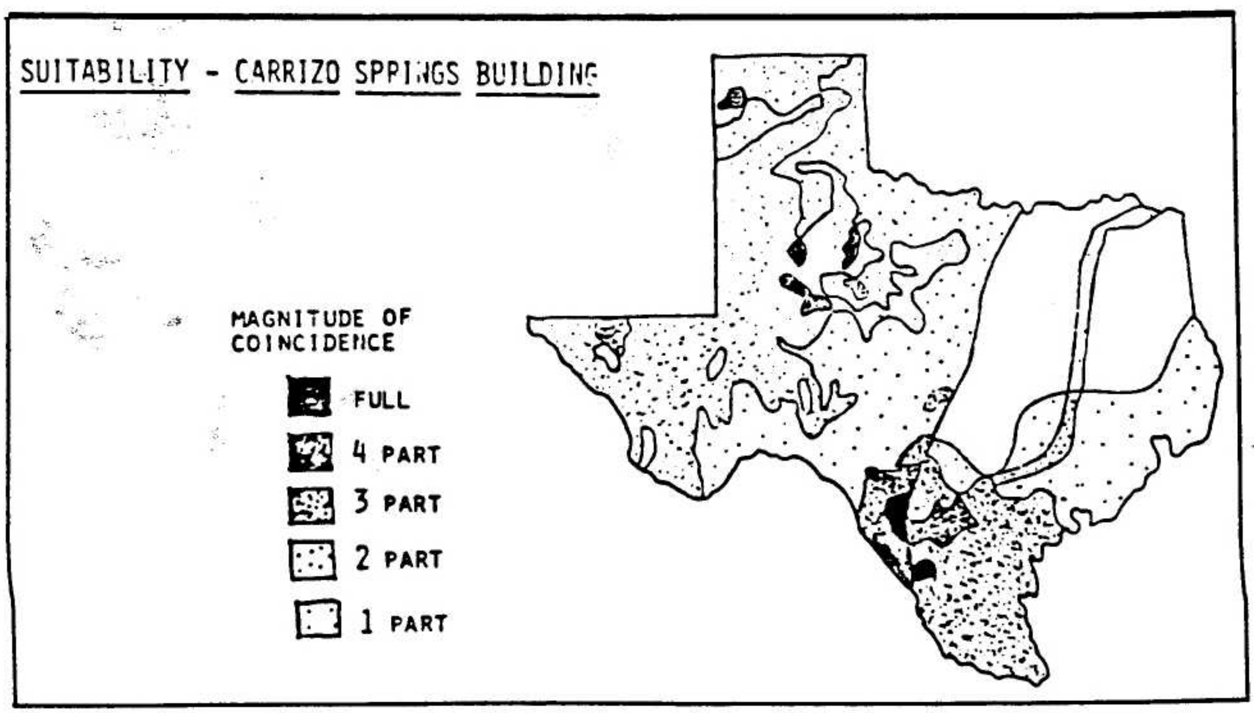
Home for abused and neglected children built from caliche block. Designed and engineered by CMPBS.

CONCLUSIONS FROM CASE STUDY

The chart on the next page compares the energy costs of conventional and indigenous wall units and foundations. The comments in the right hand column clearly show that indigenous materials use far less energy and create far more jobs than their conventional counterparts.

We found that bamboo takes approximately 170 times less energy to produce than its equivalent in steel reinforcing bar. If all fabrication methods are properly followed, bamboo will take about 18 thousand pounds per square inch (p.s.i.) tension as compared to common steel at 23 thousand p.s.i. Our cantilevered lintels and our roof trusses are under tension and we have strong reason to believe that they will last for 50 years.

Similar comparisons can be made for other properties as in a material's ability to store heat or cold. Caliche walls contain more heat capacity than conventional brick walls but require only 25% as much energy to fabricate.



A COMPARISON OF THE ENERGY AND LABOR COSTS OF CONVENTIONAL AND INDIGENOUS BUILDING TECHNIQUES

Total Wall Composition: Calcrete block insulated with mesquite sawdust block vs. fired brick with batt insulation and sheetrock.

Building Component	Indigenous	Conventional	Comments
Masonry	Pozzolan Calcrete Brick 2,279 Btu/SqFt of Wall and .28 Hour(H)/SqFt	Fired Brick 105,004 Btu/SqFt of Wall and .16 H/SqFt	Indigenous 46 times less energy intensive and twice as job intensive as conventional wall.
Insulation	Mesquite Sawdust Block 11,217 Btu/SqFt .28 H/SqFt	4 Inches Insulation 8,345 Btu.SqFt .013 H/SqFt	Indigenous 1.3 times more energy use but creates 21 times as many jobs
Other (Wood, Paint, Building Paper, Gypsum)	Exterior Latex Paint ? Btu/SqFt ? H/SqFt	Other Wall Materials 34,699 Btu/Sq/Ft and .051H/SqFt	Indigenous only needs paint.
TOTAL	13,496 Btu/SqFt and .56 H/SqFt	148,048 Btu/SqFt and .224 H/SqFt	Indigenous wall ten times less energy use and creates 2.5 times as many jobs as conventional wall.

Total Foundation Composition Including Radiant Floor: Calcrete with bamboo reinforcing vs. concrete with rebar.

Building Component	Indigenous	Conventional	Comments
Masonry	Pozzolan Calcrete* 43,797 Btu/SqFt of Building and .16 H per SqFt	Concrete* 88,935 Btu/SqFt and .04 H/SqFt	Indigenous two times less energy use than concrete and creates four times the jobs.
Reinforcing	Bamboo* 680.9 Btu/SqFt of Building and 1.55 H/SqFt	Steel Re-Bar* 8,772 Btu/SqFt Steel Mesh* 18,865 Btu/SqFt Total: 27,637 Btu/SqFt and .74 H/SqFt	Indigenous 171 times less energy use than steel reinforcing. Bamboo gives 2.1 more local jobs.
TOTAL	44,477 Btu/SqFt 1.71 H/SqFt	106,562 Btu/SqFt .78 H/SqFt	Conventional foundation uses 2.4 times the energy and indigenous creates 2.2 times the jobs.

*Includes energy for labor.

EQUIPMENT

The equipment needed to build with these materials is quite different from that normally associated with the building industry. The machinery has to be highly responsive to the specific characteristics of a region's materials and to the technical capabilities of the local population. One can begin to see how our interactive matrix discussed earlier is needed to determine a technology appropriate to a specific regional condition.

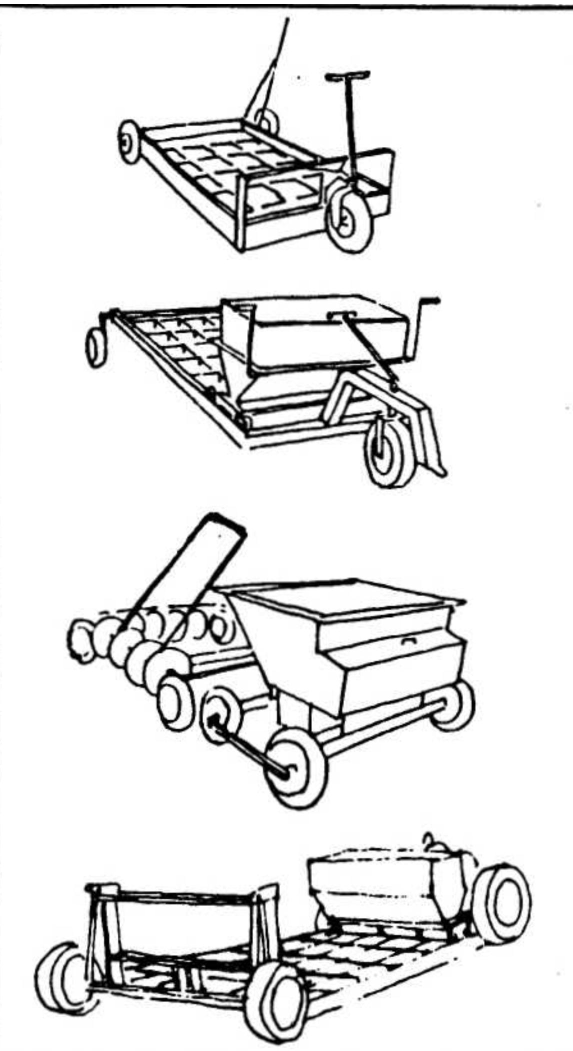
Surprisingly, most of the equipment and construction techniques presented below are widely considered to be new. However, many of them are based on ancient techniques. While we can't possibly discuss all of the indigenous building techniques and devices, we offer a representative sampling to give an idea of how regional conditions can be met.

PUDDLE BLOCK TECHNOLOGY

Puddle block is a generic term for building blocks made by pouring a moist material into a form and allowing the blocks to dry. Although the process is an ancient one, many variations have evolved from the traditional hand released gang mold.

For instance, while two people with hand molds can produce about 200 blocks per day, the Mini-Molder, developed by Howard Scoggins of Alamagordo, New Mexico, can produce 300 to 500 blocks per day. The Mold Master (a Mini Molder with travelling hopper) can produce 1,000 to 5,000 blocks per day (depending on size) using five laborers. The Mudder-Cutter (an overgrown pizza cutter), developed by Jack Dameron of Austin, Texas, has the capacity to produce from 5,000 to 10,000 blocks per day using five to six laborers. This machine lays a continuous ribbon of earth (or cement aggregate) about four feet wide, which is then sliced horizontally and perpendicularly by a set of round blades. Another device similar to the Mold Master was designed by Hans Sumpf of Madera, California. This machine has a peak capacity of 18,000 blocks per day using a seven person crew. Equipment costs, complete with trucks, front end loaders, pumps, etc., run between $200,000 and $250,000. Rumor has it that a new machine, similar in production capacity to the Sumpf, has been developed by Howard Scoggins.

These puddle block machines are easier to operate and maintain, and produce bricks of comparable strength (depending on the earth material used) to facilities which produce concrete block or fire bricks in kilns. The energy costs of puddle blocks are lower also. A comparison



Top to bottom: Mini-Molder, Mold Master, Mudder-Cutter and the Hans Sumpf machine.

of energy costs of traditional building techniques with soil cement building and rammed earth appear, below. The importance of energy costs will escalate as the dollar costs for energy increase.

These low energy block making methods do require considerable skill. One needs to understand the stabilizer needs of a particular earth and how the combination of indigenous materials can sometimes fulfill that need. For instance, we have successfully stabilized caliche with lime and pozzolan (no cement), pozzolan with lime and sand, and we've even made blocks from nothing but fly ash, sand and water that withstand 8,000 p.s.i.

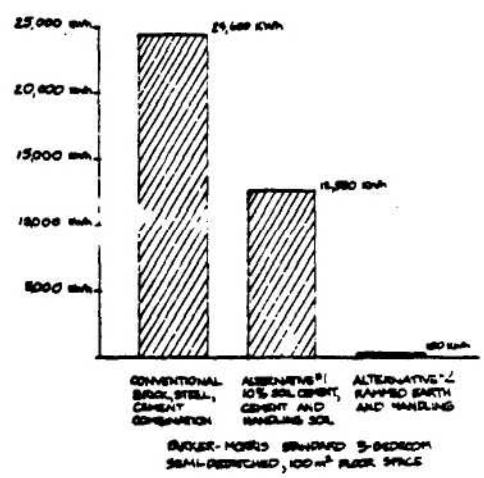
By really understanding an earth material you can transcend traditional earth building techniques. For instance, a good caliche, 80% to 90% calcium carbonate, will need only 5% to 7% cement (with an average compression strength of 960 p.s.i.), as compared to 10% to 16% cement needed for typical soil/cement combinations. Other skills such as understanding the precise amount of water required by liquid limit and slump tests, determine whether much of the equipment cited above will even work.

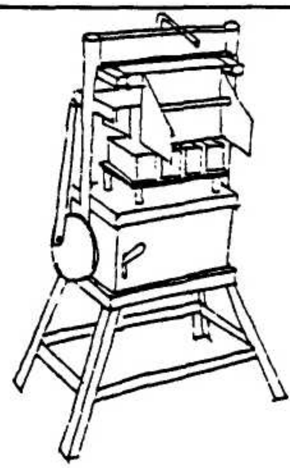
Puddle block methods do have their disadvantages. One is the large amount of space they require. The biggest drawback is probably their water requirement. For every cubic yard of material produced, about 22 gallons of water are needed. Since earth block structures function best in arid and semi-arid zones, this water requirement can be a significant problem. While earth materials require far less water than steel and concrete, we still need to keep this limitation in mind.

The fact that each of these earth techniques is adapted to a specific mix of social and natural resources is brought home by the Mexican cement block machine illustrated below. This machine makes block composed of a lightweight volcanic aggregate (of which there are extensive deposits around Mexico City) mixed with cement. Using a vibrating motion and a small amount of pressure this machine makes blocks that can be stacked immediately after they are molded. In an urban area where space is limited this is ideal because the blocks can be stacked at the end of the street as they are made. The other processes described above wouldn't work in this situation because they produce long ribbons of

ENERGY USE OF SEVERAL BUILDING TECHNIQUES

In 1940, conventional building cost 48.8% more per square foot than earth construction. By 1975 conventional construction cost 215% more than earth construction. In 35 years earth construction costs have increased 97% while conventional construction costs have risen 315%. This is because the prime increase in earth construction is labor, while in conventional building, energy and materials costs have increased dramatically in addition to labor costs.





Mexican brick machine.

brick which take up lots of room and must dry before being stacked.

Another feature of this machine is the small amount of physical labor it requires. No forms have to be lifted and since the blocks are about one-third the size of adobes they aren't very heavy. So, built around specific space requirements and locally available materials we find a machine that can produce 6,000 blocks per day with the labor of ten people. Incidentally, women were running the operation that we saw in Mexico City.

RAMMED EARTH BLOCK MACHINES

Because they skirt many of the problems of puddle block machines, rammed earth block techniques are receiving renewed interest today. They pose virtually no space storage problems since the ramming equipment can be used on any site where the soil has a 20% to 55% clay content. A flat yard is not required as with puddle block methods. And perhaps most importantly, little water is required.

Several ramming machines have been developed over the years. Perhaps the best known is the Cinva Ram. However, I have found this hand operated unit to be extremely frustrating and tiresome to work with. It only produces 300 blocks per day (if you're lucky) and it produces a block far stronger than

Top to bottom: Cinva Ram, Winget Works, Hallomeca, M & M Metal Company, Brostholm.

is needed. Caliche blocks can come out of a Cinva Ram with a compression strength of 1, 400 p.s.i. which is enough to build an eight story building. I must say that we don't see the future of the brick industry in the Cinva Ram.

However, there are some good rammed block machines available. In the 1950's the Winget Works in England invented the Winget pressed block machine which produced 1,120 blocks per day. Its only drawbacks were its weight and the inability of small equipment to efficiently move it from site to site.

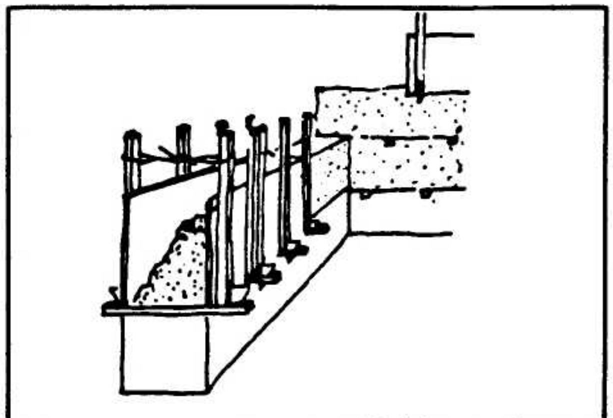
A more recent development is the Hallomeca, from France. It has a production rate of 8,000 to 16,000 blocks per day. Not much is known about this machine in the U.S., but information on it can be traced through one of the French earth building groups cited below.

Recently, in the U.S., the M&M Metal Company introduced an hydraulic unit using a 200,000 p.s.i. press. The machine is mobile, contains an integral mixer and produces about 2,000 blocks per day. However, its reputed use of 5% to 70% clay materials seems to be incorrect in that we received a shipment of 7% clay block of which about one-third arrived damaged. We suspect, though, that this machine will make an excellent block when using soil with higher clay content. Its major drawback is cost: $50,000 plus front end loader.

One can also track down the German Brostholm; a stationary pressed block machine with a reported production rate of 10,000 to 72,000 blocks per day. For more information on the European machines mentioned here, contact: Centre d'Etude du Batiment et des Travaux Publiques, 12 Rue Brancion, Paris 15; Group de Recherche et d'Echanges Technologiques, 34 Rue Dumont d'Urville, 75016 Paris; and TTL Technologie Transfer, Leistelle am I.P.A., Holzgartenstir 17, D-7000, Stutgart 1 Germany. Also consult the bibliography cited at the end of this article.

RAMMED EARTH WALLS

Another earth building technique growing in popularity is that of the rammed earth wall. This is an ancient technique going back in the U.S. to at least 1773 and in the Middle East to the time of Hannibal 247 B.C. Various modifications of this technique have been developed



Rammed earth building form.

over the centuries. They all use some kind of vertical form mounted over the foundation into which earth is placed and tamped. Entire walls and even entire building shells can be rammed as one solid piece. As with rammed earth blocks, this process has the advantage of being adapted to almost any site and it uses very little water.

This technique can be very fast. With the use of a front end loader and pneumatic tampers, entire building shells having been known to go up in one day. But this equipment is expensive and thus adds to the cost of the process. However, all of the fabrication techniques discussed here require some equipment. So to properly compare the different techniques, you must consider prices of the materials and equipment as well as the skills required and construction procedures used.

THE FUTURE OF INDIGENOUS BUILDING MATERIALS

To envision a future for indigenous building materials there must be sufficient evidence that the emerging state of the art as described in this paper forms both practical, immediate solutions while solving basic problems that previous attempts have been unable to do. Our success in Texas leads us to believe that indigenous materials hold just such a promise. Ready material availability, low energy cost, simplicity of equipment, and flexibility in production rates give indigenous materials a pretty rosy future.

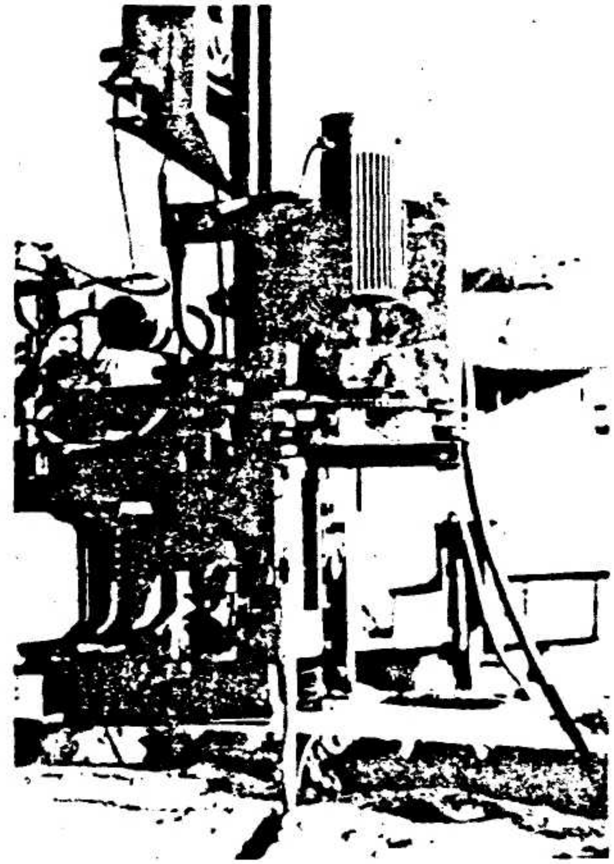
But many questions still remain and these go well beyond even our present building technology standards. We need to look at the recyclability of materials, once a structure's useful life is over. We should consider the flexibility of structures in response to changing uses. Issues of psychological and group response to the scale of space is proving to be more of an influential factor on the long term success of buildings than was first imagined. Yet, few means to cope with this issue exist in the context of present building methods.

The list could go on. The main question before us, though, is how a concentrated effort on the development of indigenous materials places a different light on the future of building in general and offers solutions to some of the problems outlined above.

It is obviously difficult to bolt or unbolt earth. It is difficult even to move it. But these questions reflect a narrow mindset of what building technology is all about. We must think on a different plane. We must consider the inherent characteristics of the materials we are using.

Let us begin with a simple, straightforward way to open our minds to some of the potentials. The landscape around us already possesses major structural forms. Why create more? Why add our ticky, tacky, usually ugly way of dealing with the built environment to the major forms which exist around us and could lead us if we would only let them?

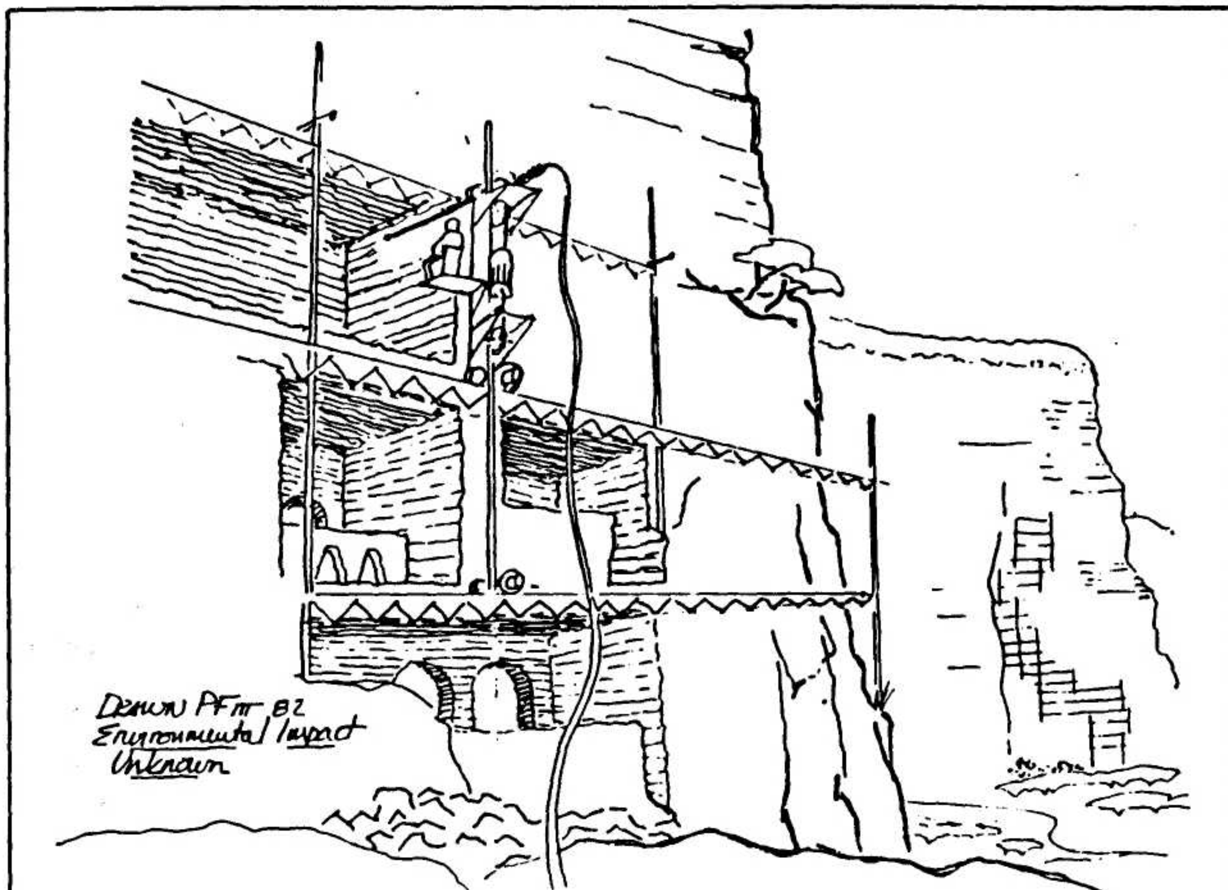
Availability? There is probably more massive rock in the form of mesas than there is earth in many parts of the western states. Energy use in building? Recent work with simply spraying water at very high pressure



Water jet cutting granite in a quarry.

from 5,000 to 25,000 p.s.i. has shown that massive amounts of rock can be cut at relatively high speed using 1/500th the energy needed to produce concrete block of similar size. But why produce block at all? Using technology from the mining industry we can build into cliffs and mesas. Simply leave your walls and cut your doors, windows and stairs. The technology to do this exists today, recycles water back into the jet and is small enough to fit into a pick up truck.

But we can go even farther in our pursuit of recyclability, reversability and human responsiveness. If indigenous materials existed that could be built into appropriate forms and then dissipated, our goals could possibly better be realized than by using rock. Let us look at two contenders: sulphur and calcium, respectively the 14th and 5th most available elements on Earth.



Pliny Fisk's conceptualization of water jets carving buildings out of a cliff.

Depending on location, sulphur can be collected at surface, mined using the Frasch mining process, or collected from coal combustion generating plants as a result of emissions control. At a national level, in 1973, 16 million tons of sulphur dioxide were emitted into the atmosphere and 33 million tons were produced by other means.

It is also interesting to note that in 1973, 75.4 million tons of concrete were used in the U.S. This is important when one realizes that cement can be replaced by sulphur at up to 80 times less energy cost. Sulphur also has other qualities that make it uniquely suited to our criteria of wide availability and flexibility.

But sulphur's most impressive characteristic is its chemical composition. Essentially, it is a thermoplastic. This means that it can be melted and formed, then remelted and shaped into a different form. Sulphur can be sprayed into shell structures where design compression strengths can be as high as 6,500 p.s.i. (as compared to 2,500 to 3,400 p.s.i. for concrete). You can form it into insulation. You can color it and even transfer inks from printed materials directly into its surface. Sulphur is 100% water resistant and therefore usable for tanks, cisterns, and boats. And, it is an effective natural pesticide. Buildings and entire communities can be built out of sulphur and then remelted, reshaped, moved or even returned to the earth after their useful life is over.

Calcium is another readily available and extremely versatile material. Calcium carbonate comprises approximately 14% of the Earth's surface on land and as ocean reefs. Calcium carbonate and brucite, among other minerals, can form a rock hard (4,200 p.s.i.) surface when electrolytically accreted onto wire mesh. This process simulates the formation of ocean reefs. Recent experiments using relatively low amounts of energy (1 kw/ 1/9 kg of material accreted) show the feasibility of fabricating artificial reefs, boat hulls, island extensions, off-shore stabilization, land reclamation, and more.

As with sulphur, structures of this material can be dissipated, by reversing the electrical current. Thus, this process has the potential to adapt a structure to a wide variety of environments and can continually respond to changing human needs.

As the structure ages and begins to have selective failure, selective electrolysis can reaccrete more material and repair the damage in much the same way that bones are healed.

We've presented a lot of information here, both on work already in progress and on ideas that could well lead to major changes in the way we conceive and construct our built environment. It is impossible to reference all the information presented here in a concise bibliography. We have prepared for sale an extensive 50 page
bibliography on indigenous building materials We would also appreciate any comments readers may have on this paper. Many of the topics presented here and the buildings referred to are ones with which we are directly involved. Please get in touch with us if you are interested in pursuing this work. Our organization's survival is dependent on such support.

Calcium carbonate precipitating onto a wire armature which was suspended in the sea.

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