EARTH BLOCK MANUFACTURING AND CONSTRUCTION TECHNIQUES

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CENTER FOR MAXIMUM
POTENTIAL BUILDING SYSTEMS

AUSTIN, TEXAS

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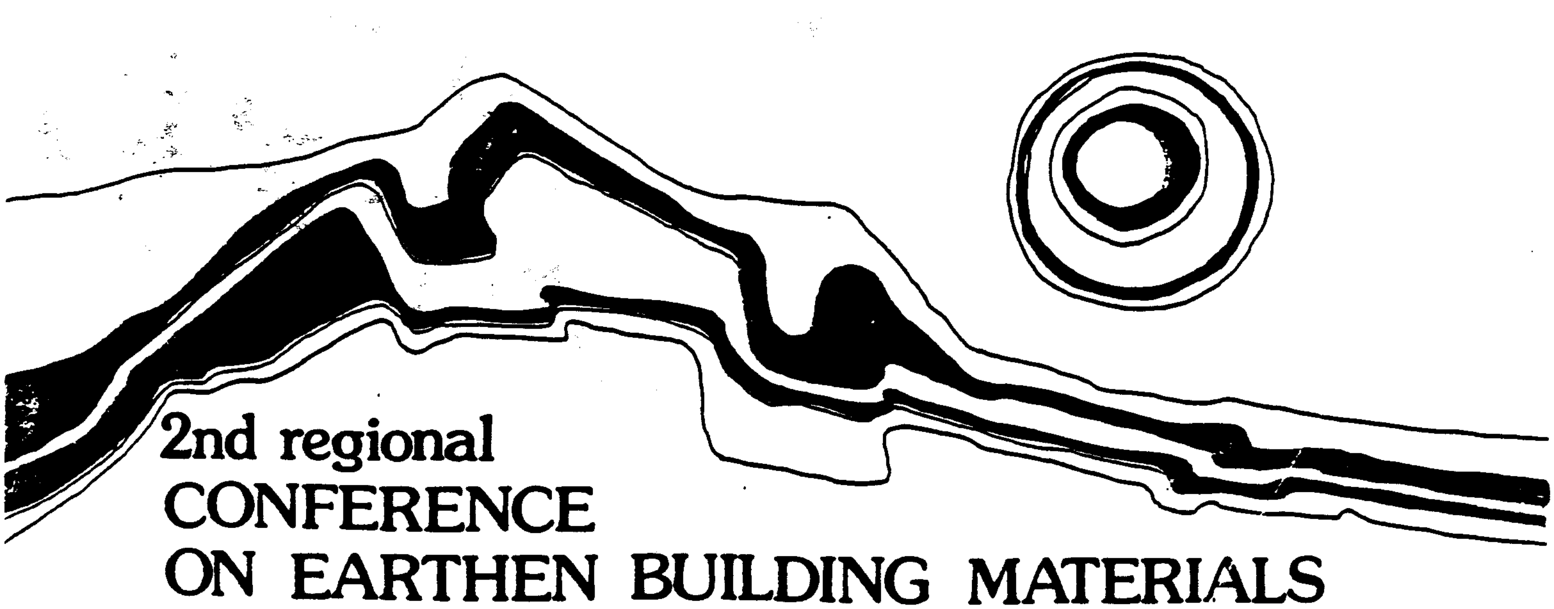
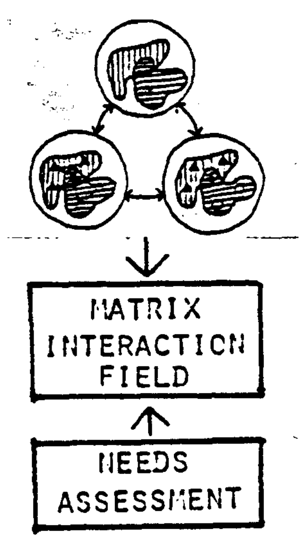
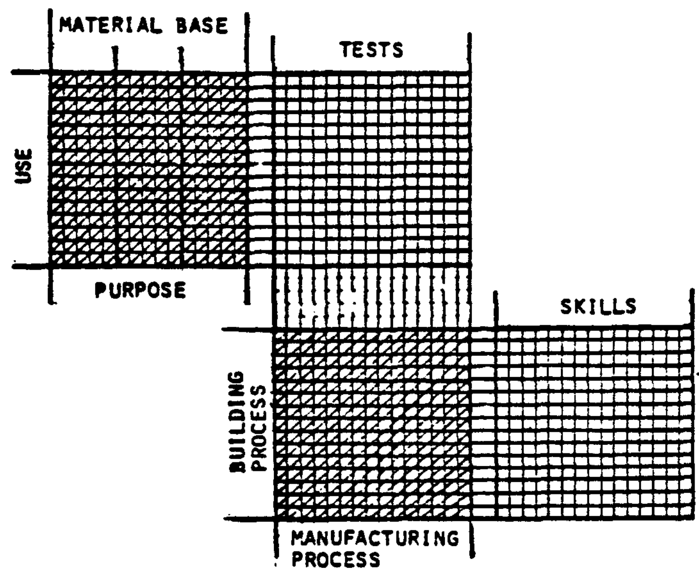


In the paper entitled "Availability and Spatial Coincidence of Indigenous Building Materials," we outline some of the reasons why we consider spatial mapping to be so important, and also how appropriate technology efforts such as building with earth can be looked at in planning terms through this process. In this paper on building techniques, several steps in our planning process are skipped, and we begin the process with the step of inventorying a series of earth building technologies. But first let us quickly track out the planning process step-by-step.

Normally, building techniques respond not only to a full inventory of indigenous resources (what we term area resources) but also to an inventory of skills and knowledge found within an indigenous population. Such human attributes we call point resources. For purposes of this paper, this indigenous knowledge is in the regional alchemy of building with earth. A third important area to identify is the scale of trade in information, goods and services and other transactions related to a particular subject matter, such as earth, for building. We refer to such transactions as network resources--without them the society structure would not be identified in order to determine how, for example, earth materials could benefit the local economy. These three levels of resource identification--area, point and network would normally address a needs assessment as diagrammed below:

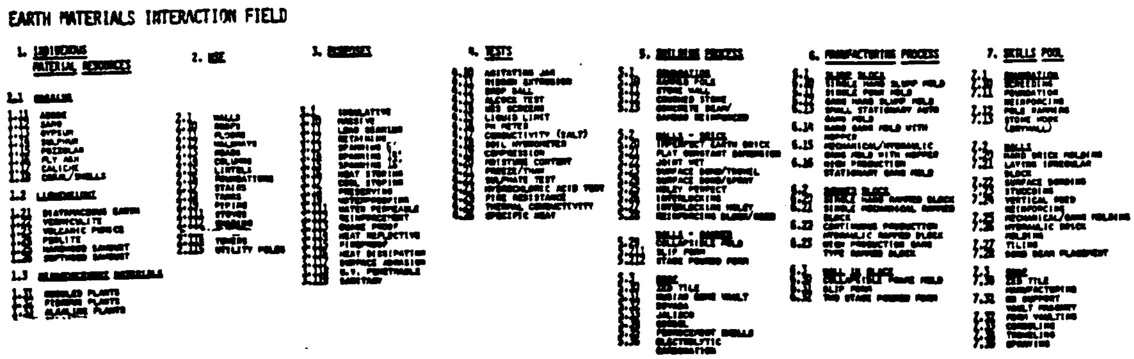


EARTH MATERIALS INTERACTION FIELD



The needs assessment determines what resources must be developed in all areas of life support, i.e. food, fuel, shelter, and 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 therefore required in the area of testing, fabrication and/or skill development.

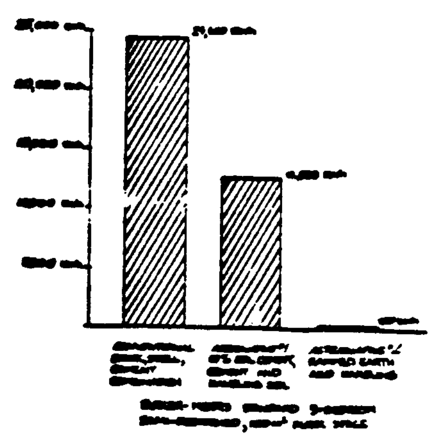
For the purposes of this paper, we will not dwell on the topic of cross-referencing. However, we hope the interaction field establishes within the readers' mind the variables in question when choosing or developing a technological component. In order to make this planning process useful, let us consider it a kind of checklist or self-tracking methodology, only one part of which is about to be presented.



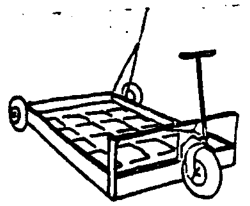
Probably one of the oldest and simplest earth building techniques is producing block. The chart below outlines block manufacturing processes. These methods have been chosen since many variations have evolved from the traditional simple hand-released gang-mold. For instance, while two people with hand-molds can produce about 200 block per day, the Mini-Molder, developed by Howard Scoggins of Alamagordo, N.M., can produce 300-500 block per day. The Mold Master (a Mini Molder with travelling hopper) can produce 1,000-5,000 block per day (depending on size) using five laborers. The Mudder-Cutter (an overgrown pizza slicer) developed by Jack Damerorr of Austin, TX. , has the capacity of producing from 5,000-10,000 block per day using five-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. The perpendicular cut is done manually using a large handle. Also available is a large Mold-Master type machine, which was originally designed by Hans Sumpf of Madera, CA. (Ironically, madera is Spanish for wood.) This machine has the peak capacity of " popping" up to 18,000 block per day using a seven person crew. Equipment costs, complete with trucks, front-end loaders, pumps, etc., run between $200,000-$250,000. Rumor has it that a new machine, similar in production capacity to the aforementioned Sumpf, has been developed by Howard Scoggins.

The distinct advantage of these slump-block machines is that they are simple and straightforward to operate and maintain relative to machines producing block which require the use of brick kilns or even concrete block manufacturing facilities, yet they offer a block of comparable] a strength (depending on the earth material used).

Energy costs of these puddle block are also comparatively cheaper with a low of $.04 \times 10^6$ BTU per cubic yard of puddled material, while a concrete block runs 14×10^6 BTU per cubic yard. A comparison for a traditional soil cement building and rammed earth structure appears below. Of course, the importance of energy costs will escalate as they are reflected in dollar values.



SLUMP BLOCK MACHINES



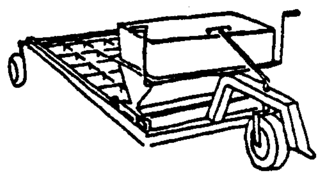
COMMERCIAL AVAILABILITY: YES [X] NO [ ]

PLANS AVAILABLE: YES [ ] NO [X]

ADDRESS: Howard Scoggins c/o Adobepatch
RR1, Box 240
Alamagordo, NM 88310

MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:

BASE MATERIAL: PRODUCTION RATE:
BLOCK TYPE: CAPITAL COST:



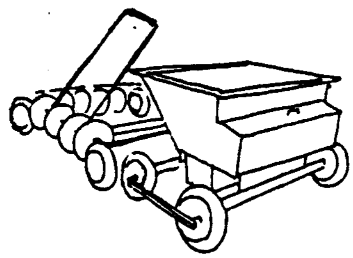
COMMERCIAL AVAILABILITY: YES [X] NO [ ]

PLANS AVAILABLE: YES [ ] NO [X]

ADDRESS: Tejaco
13611 N. IH 35
Austin, TX 78753

MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:

BASE MATERIAL: PRODUCTION RATE:
BLOCK TYPE: CAPITAL COST:



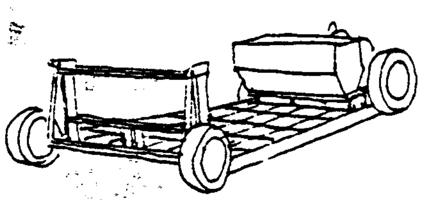
COMMERCIAL AVAILABILITY: YES [X] NO [ ]

PLANS AVAILABLE: YES [ ] NO [X]

ADDRESS: Tejaco
13611 N. IH 35
Austin, TX 78753

MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:

BASE MATERIAL: adobe/caliche PRODUCTION RATE: 5-
BLOCK TYPE: poured block CAPITAL COST:



COMMERCIAL AVAILABILITY: YES [X] NO [ ]

PLANS AVAILABLE: YES [ ] NO [X]

ADDRESS: c/o Howard Scoggins /Adobepatch
RR1, Box 240
Alamagordo, NM 88310

MOBILITY: YES [ ] NO [X]
HAULING REQUIREMENTS:

BASE MATERIAL: PRODUCTION RATE:
BLOCK TYPE: slump block CAPITAL COST:

The catchall to these low energy block-raking methods obviously depends on one's in-depth understanding of earth materials. Usually, the better one understands the stabilizer needs of a particular earth and how the combination of indigenous materials can sometimes fulfill that need, the more realistic one's operation is apt to be over the long run. For instance, we have stabilized caliche with lime and pozzolan, pozzolan with lime and sand, and some fly ash with nothing at all, just adding water and sand and still getting 8,000 p.s.i. in two weeks.* (We'll keep that flyash a secret for awhile). The point is that by really understanding an earth material, you can get around traditional earth building techniques. For instance, a good caliche, 30-90% calcite carbonate, will need only 5-7% cement, (with an average p.s.i. of 960) as

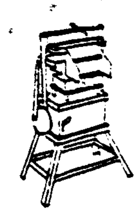
*There are several flyashes found to have this quality, especially derived from coal coming from Colorado, i.e. Corranche Peak Power Plant, CO. The test for the sample cited was done by Jimrny Jarl, Texas Cement Products Testing, Lab, Buda, Texas.

compared to 10-16% 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 will even work.

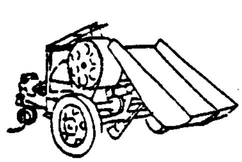
Similarly, disadvantages to puddle block fabrication methods are also apparent. One is the space requirement for production; another, and probably <u>the</u> biggest disadvantage, is the water requirement. For every <u>cubic yard</u> of material produced, about 22 gallons of water are needed. When one realizes that earth block structures function best in arid, semi-arid zones, this water requirement could turn out to be their downfall. Of course, the degree to which earth materials are better in this regard than buildings of steel and concrete is an important concern, but one which we'l1 not pursue here. The fact that building with earth is better than conventional modern materials should not let us lose sight of the problem posed by the water requirement.

The fact that each of these earth techniques carry with them a specific social/resource fit is brought some by the Mexican cement block machine shown below. This machine makes block composed of a lightweight volcanic aggregate (of which there are extensive deposits around Mexico, City) mixed with cement, and features a vibrating motion and a small amount of pressure.

CEMENT BLOCK MACHINES



COMMERCIAL AVAILABILITY: YES [X] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: c/o Sra. Socorro Velasco
Instituto Nacional Indigenista
Av. Revolucion 1279, Mexico 20, D.F.
ref. by: CMPBS
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS: Pickup
BASE MATERIAL: cement (pumice) PRODUCTION RATE: 6000/dy
BLOCK TYPE: CAPITAL COST: 1200



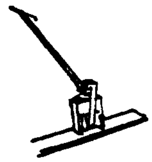
COMMERCIAL AVAILABILITY: YES [ ] NO [X]
PLANS AVAILABLE: YES [X] NO [ ]
ADDRESS: c/o Mother Earth News
Issue: May/June '77
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS: Pick up
BASE MATERIAL: cement/voc. ash PRODUCTION RATE: 100/hr.
BLOCK TYPE: CAPITAL COST:

Because of these two functions, the vibration and pressure, the block produced by this machine can be stacked immediately after they are molded. In this case, the stacking occurs at the end of a street in an urban area. Another feature of this machine is a minimal physical labor requirement: no lifting of forms nor carrying of big blocks, for the block are about a third the size of adobe block. So, built around specific space requirements and user type and materials we find a machine designed, and which, with the labor of ten women, can produce in the order of 6,000 block per day.

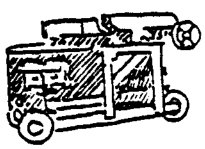
The Hi Siboy machine pictured next is similar to the Mexican machine but is no longer available, perhaps because everything was put into one unit: material lift bucket, sifter, mixer, etc., which may have rendered it too complicated. Only 300 block per day were produced.

Because they skirt many of the problems held by the machine reviewed above, rammed earth block techniques are receiving renewed interest today. They pose virtually no space storage problem since the ramming equipment can be brought to any site whose soil has 10-60% clay content; a flat yard is not required as with puddle block methods; and, perhaps <u>most importantly</u>, is that <u>little water</u> is required. Several ramming machines have been developed over the years, perhaps the most reknowned being the Cinva Ram. This hand operated unit, however, is, to me, extremely frustrating, and is equally frustrating to a crew trying to do a good day's work without breaking their backs. To get to the point, the Cinva Ram boasts an output of 300 block per day (if you' re lucky), producing an over-stressed block (caliche block can core out at 1,400 p.s.i.)--enough to build an eight plus story building, which one rarely does in our field of endeavor. I must say I don't see the future of the brick industry here.

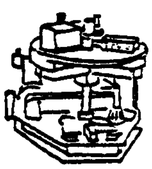
RAMMED EARTH BLOCK MACHINES



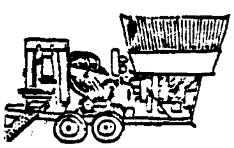
COMMERCIAL AVAILABILITY: YES [X] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: CINVA RAM/ELLSON BLOCK MASTER
c/o INTER AMERICA HOUSING & PLANNING CTR, BOGOTA, COLOMBIA
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:
BASE MATERIAL: ADOBE/CALICHE — PRODUCTION RATE: 325/DAY
BLOCK TYPE: PRESSED BLOCK — CAPITAL COST: 350



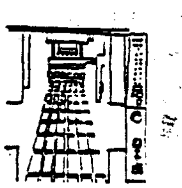
COMMERCIAL AVAILABILITY: YES [ ] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: c/o Hallumeca/CRATerre
Haut-Brie - 38320 Eybens
FRANCE
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:
BASE MATERIAL: — PRODUCTION RATE: 8-16,000
BLOCK TYPE: — CAPITAL COST:



COMMERCIAL AVAILABILITY: YES [ ] NO [X]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: Winget Works
Rochester, ME 2AA
Great Britain
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:
BASE MATERIAL: — PRODUCTION RATE: 1120
BLOCK TYPE: pressed block — CAPITAL COST:



COMMERCIAL AVAILABILITY: YES [X] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: Earth Ram c/o M&M Metals
2129 Country Club Drive
Mesa, AZ 85201
MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS: large pickup
BASE MATERIAL: 10-60% clay — PRODUCTION RATE: 2,000/day
BLOCK TYPE: block type — CAPITAL COST: $50,000

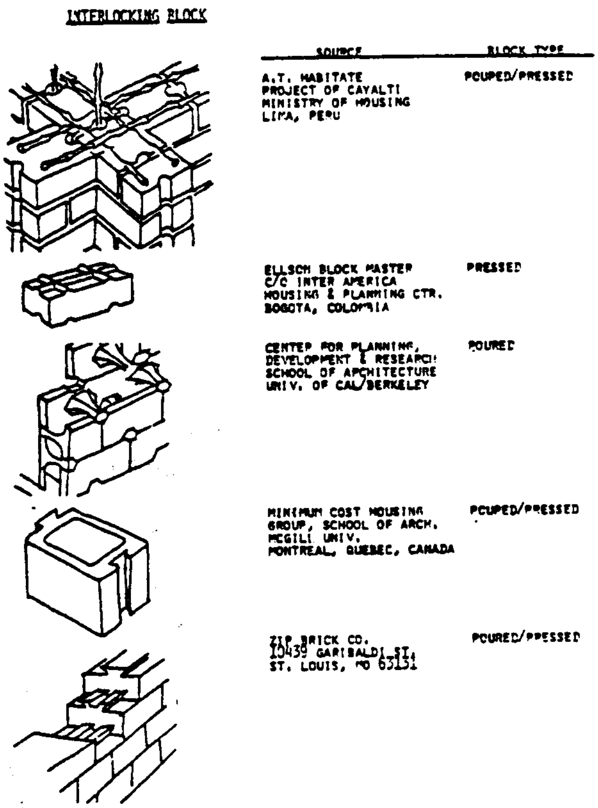


COMMERCIAL AVAILABILITY: YES [X] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: c/o Brostholme/CRATerre
Haut-Brie - 38320 Eybens
FRANCE
MOBILITY: YES [ ] NO [X]
HAULING REQUIREMENTS:
BASE MATERIAL: — PRODUCTION RATE: 10-72,000/day
BLOCK TYPE: pressed block — CAPITAL COST:

In the 1950's, Winget Works in England came up with the Winget pressed block machine, which probably was the beginning of an entire line of this type of effort. The Winget's production rate was decent at 1,120 block per day, and its only drawbacks were its weight and the inability for small equipment to efficiently move it to a site. A more recent development has been that of the Hallomeca from France which has a production rate of 8,000 to 16,000 block per day. Not much is known about this machine in the U.S., but information on it can be traced through one of the earth building groups in France as one should probably do as well for the Brostholm, a German stationary pressed block machine with a reported production rate of between 10,000 to 72,000 block per day. For more information, contact: Centre d'Etude du Batiment et des Travaux Publics, 12 Rue Brancion, Paris 15; Groupe de Recherche et d'Echanges Technologiques, 34 Rue Dumont d'Urville, 75016 Paris; & TTL Technologie Transfer, Leistelle am I.P.A., Holzgartenstir 17, D.7000, Stuttgart 1.

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

We would like to follow the section on rammed block machines with the concept of interlocking mortar-free block since we believe the two concepts to be compatible and, in fact, have already been incorporated by the Ellison hand-operated machine. Basically, interlocking block are uniform and possess details which enable them to be completely interlocked with each other without the use of mortar. It is even possible with a good system to accomplish this at corners.

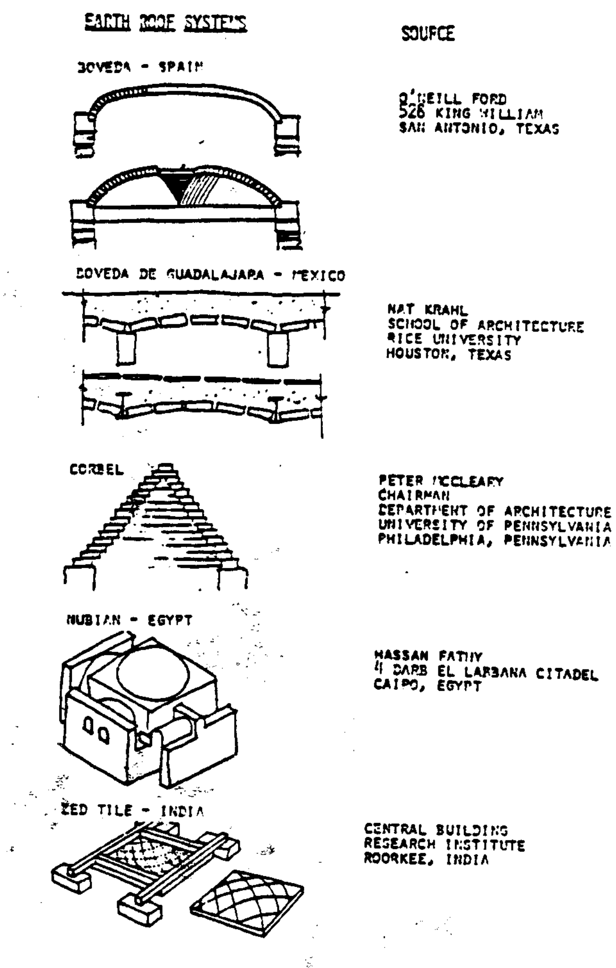


Our first example is actually a puddled block with a hole system capable of utilizing bamboo as vertical reinforcement; in our opinion an excellent application if the bamboo is properly treated for rot. The only potential problem we for-see is misaligning the block during construction. By its nature, the process of puddling earth is a sloppy one, and if one does not admit to its inherent sloppiness (i.e. large holes) one can easily get into trouble in this process.

On the other hand, pressed interlocking block can begin to acquire the manufacturing precision necessary for interlocking at least in one dimension. In order for <u>both</u> dimensions to acquire dimensional stability, though, precise moisture control would be needed which this author believes might be attainable with an electronic sensor placed within the block cylinder walls, coupled with a feedback control adjusting the amount of pressure supplied by the hydraulic system. One could imagine at least two of the four systems outlined as possible candidates for earth pressed block equipment.

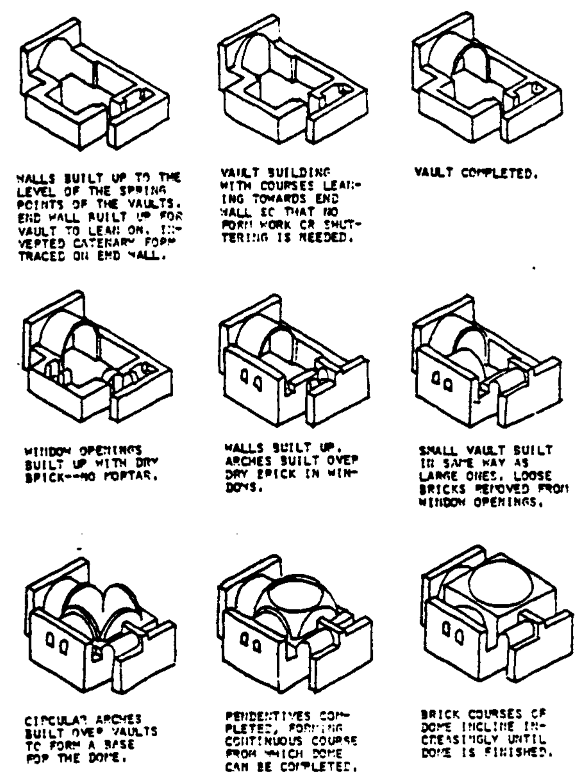
Before moving on to our final topic, roofs, we would like to mention the social/family implications of building, especially with earth walls. One reason for raising the subject of earth block is the potential for self-help. By building as one needs and not borrowing money, considerable savings are realized. Further, if interlocking earth block were to be efficiently developed, another important social dimension, that of flexibility, is addressed. Being able to add a room for grandmother and then disassemble and sell the brick or change room dimensions as the need for room may change would become a technical reality. Even building a structure and gradually changing it to fit changing spatial needs, and then finally stabilizing it with one of a number of surface finishes is also possible, as was the basis for an entire Peruvian building competition based on the Berkeley brick described in the chart.

Cultures forced to reduce their dependency on wood have made important contributions with their earthen roof systems. When properly constructed, these roof are reported to withstand earthquakes, but each technique has its own particular attributes. Here are some we have collected information on over the years along with references so you can obtain additional information.



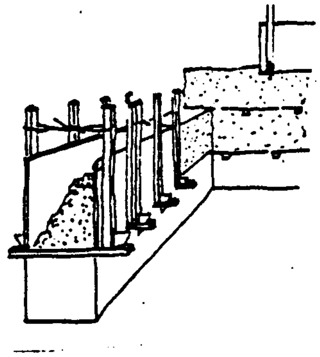
The Boveda referenced through O'Neill Ford's office in San Antonio is used in central Texas and constructed by crews from Mexico, and is reportedly of Spanish origin. Its structure, however, is somewhat of a mystery, in that Felix Candilla has tried but has been unable to analyze its properties. The mystery is that forces from such a flat dome would appear to exit on an angle on the periphery, but there is no need for a ring to surround the dome since, in actuality, the pressure is translated straight down.

The Nubian dome uniformly distributes weight, so that as you progress to the top, each section of the dome has equal downward thrust, again placing no outward pressure on the walls at the dome base. This is an important feature in case of failure, in that the center will not collapse due to the sides giving way radially. On the other hand, the Boveda de Guadalajara directs all its forces to the edge. It is a flat dome and, as such, is frequently used as a form for pouring concrete over in high rise modern buildings. It is not, however, an inherently structural system of good quality and is therefore unusable in itself with other low technology methods.

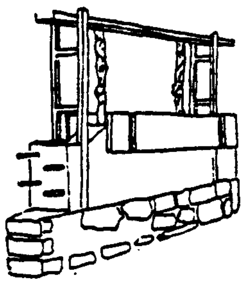


Corbelling is a roof system that utilizes a ratio of the cantilever weight to the inherent weight of each block in order to form a cone-shaped vault. Unlike the Nubian, it requires no mortar and has been constructed solely of rock. For these reasons, the Corbel is easier to build than the Nubian or Spanish Boveda, but its weight can be problematic, since the weight of each block is not incorporated into a shell-type structure as with the mortar-glued techniques.

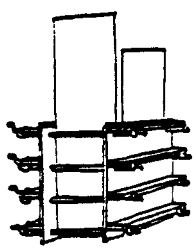
The final roof brick technique we will present uses what is called a zed tile. It differs from those described above since it requires a primary structural system in order to lay these 2' x 2' tile onto. When properly mixed, the shells themselves are a fail-safe system in that a perfect parabola is formed by the weight of mortar poured and trowled onto a burlap covered frame, first on a flat surface and then, 20 minutes later, on end-supports in order for the center to achieve its structural shape. The small shell is then turned upright and pivoted so that the sides are low and on the supports. Then, a concrete fill is poured over the tile making the roof and floor. The zed tile is limited to cement and caliche cement techniques.



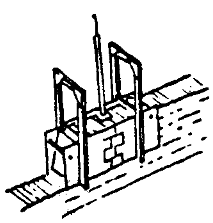
TRADITIONAL EUROPEAN
RE: CONSTRUIRE EN TERR
CRATERRE
HAUT-BRIE - 33320
FRANCE



TERRE ET POTEAUX
RICHTER POLLACK
TECHNIK DES LEHMBAUES
R.D.A., 1952



DAVID EASTON
RAMMED EARTH WORKS
BLUE MOUNTAIN RD.
WILSEYVILLE, CA 95257

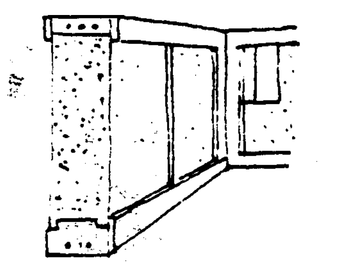


EARTH-WALL CONSTRUCTION
G.F. MIDDLETON
COMMONWEALTH EXPERIMENTAL BLDG. STATION
AUSTRALIA

Earth placed directly into the wall structure and then rammed has been a technique used in the U.S. since 1773, with records going back to the times of Hannibal in 247-183BC. Basically, four methods are utilized as drawn above. The first two are the oldest, one incorporating in French what is called the "clef" or slightly tapered stay. These stays were used to hold up the batter boards from below and were removed from the wall once the form area was finished. (The potential for developing a building system that leaves and then later incorporates these stays as part of the internal furnishings of shelving, desks, counters, outside trellis for vines, etc. remains a distinct possibility that as far as this writer knows has yet to be tried).

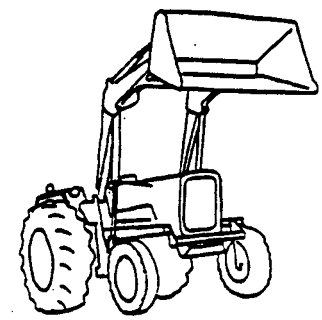
The second technique actually incorporates vertical wood supports in the wall. These are used for extra-structure but, more importantly, can be used as a connection base for the batter boards. In today's building, such a vertical column section could as well be used as a wire chase while structurally being incorporated as a post and beam system to be used for satisfying codes or for actual earthquake protection.

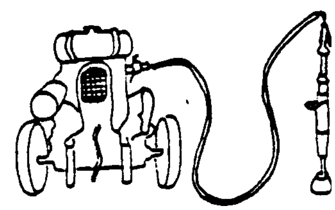
The third technique outlined is a take-off on the previous, but now the wood column sections are filled with concrete and become a continuous part of the structure tying together foundation (with vertical rebar out of slab) and bond beam, the column and bond beam all being filled with a concrete pump together. This system has been perfected and mostly developed by David Easton and group in Wilseyville, California, and was particularly suited for passing codes in that area. However, it is not necessarily needed in other regions. The form system is practical and easy for anyone to construct, being made of plywood 1" thick, 2x8 side support members that double as scaffolding and pipe clamps that hold all together.



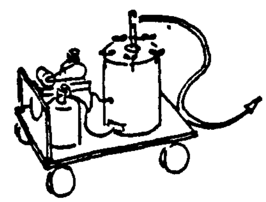
Easton Wall System as it Appears in Final Form

The final rammed earth wall construction system was developed by Midleton in Australia in 1952. It is based on the principal of a slip form, thus eliminating the need for mantling and dismantling forms. This method has even been used to construct earth domes by connecting a smaller slip form on a central Divot system (not reported in earth roof section). Each of the systems reported have advantages and disadvantages. The latter slip form system, for example, is difficult to substantiate when many window and door openings exist, and vice versa for the Easton system presented above. The speed of construction using rammed earth is most impressive with whole shells of buildings known to go up one day, but a front end loader and pneumatic jack hammer are necessary for this level of production: thus, the contractors initial cost for home building must include these expenses. However, one must remember that peripheral equipment is required for almost every fabrication technique discussed so far, and in order for one to properly compare prices, skills, and construction procedures, these must be included.





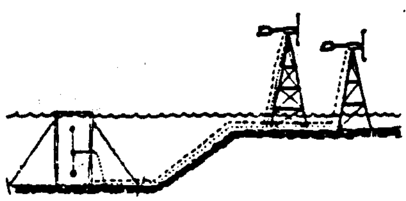
INDIGENOUS SHELL BUILDING SYSTEMS



COMMERCIAL AVAILABILITY: YES [X] NO [ ]
PLANS AVAILABLE: YES [ ] NO [X]
ADDRESS: Southwest Research Institute
San Antonio, TX

MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS: PICKUP

BASE MATERIAL: SULPHUR PRODUCTION RATE: 1 HSE/DY
BLOCK TYPE: SHELL CAPITAL COST: 12000



COMMERCIAL AVAILABILITY: YES [Y] NO [ ]
PLANS AVAILABLE: YES [X] NO [ ]
ADDRESS: WOLF HILBERTZ
MARINE RESOURCES CO.
819 BALL AVE. GALVESTON,TX 77550

MOBILITY: YES [X] NO [ ]
HAULING REQUIREMENTS:

BASE MATERIAL: CALCIUM CARBONATE
BLOCK TYPE: REEF/SHELL

We will conclude with two shell building techniques that are not normally thought of in the category of earth building, but which still utilize highly available materials. One is sulphur, the <u>fourteenth</u> most available element on Earth; the other is calcium which is the <u>fifth</u> most available element.

	Element	% by Weight of Earth's Mass
0	Oxygen	46.60
Si	Silica	27.72
Al	Aluminum	8.13
Fe	Iron	5.00
Ca	Calcium	3.63
Na	Sodium	2.83
K	Potassium	2.59
Mg	Magnesium,	2.09
Ti	Titanium	.44
H	Hydrogen	.14
P	Phosphorous	.12
Mn	Manganese	.10
F	Flourine	.07
S	Sulphur	.06
C	Carbon	.03

Sulphur can either be mined or collected from coal combustion generating plants, a result of emissions control. In 1973, 16 million tons of sulphur dioxide were emitted into the atmosphere, while the total mined sulphur in the U.S. in 1970 was approximately 10 million long tons. The obvious connection between the need for recycling this material for reasons of air pollution combined with a high potential for use as a building material make sulphur's appropriate technology applications obvious.

Traditionally, sulphur has been poured in blocks or tile shapes after being heated to 240° to 246°F and mixed with sand, plasticizer and fireproofer. In the late sixties, the Southwest Research Institute in San Antonio developed a sprayer and an insulating foamer. The latter has been taken over by Chevron Research Corporation, while the former is still custom fabricated by the Southwest Research Institute for $15,000. For the purposes of this paper, we will concentrate on the sprayer.

Spraying can be accomplished over existing forms such as reed basket-type structures, wire lath, or canvas and burlap forms. This spray technique is especially practical to use to solidify the interlocking blocks discussed earlier. The material can be reinforced with fiber as it is sprayed by simply placing a spool of reinforcing hemp, sisal, etc. within a small one foot diameter pressure tank with a removable lid. The thread is first placed over a hook in the top of the tank and then through a small venturi made out of pipe parts and placed in the top or side of the tank. Fifteen pounds of pressure in the tank will put thread out the end of the hose at 60 feet per second. The final structure can be fireproofed by covering the sulphur with gypsum plaster, which has 100% adhesion capacity to the sulphur.

The final indigenous material technology bases itself on one of the highest available materials on Earth, calcium. Earlier, we mentioned that calcium carbonate on land makes up 14% of the surface. In sea water, calcium carbonate and brucite form a rock hard (4,200 p.s.i.) surface when electrolytically accreted onto wire mesh. Recent experiments carried on by Wolf Hilbertz at the Marine Resources Corporation in Galveston, Texas show the feasibility of fabricating artificial reefs boat hulls, island growth and other applications. Energy use for this process, excluding that embodied in the wire cathode, is l kw/1.9 kg. Potential for reversing the structural process, thus actualizing dissipative environments, has been accomplished by reversing the current. The latter has potential uses to adapt the environment to different spatial uses. Finally, as the structure ages and begins to have selective failure, selective electrolysis can be used for reinforcement. Thus, the system provides for a self-mending apparatus within its structural matrix.

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- Bryce Wilde, Warner, OK: sawdust

- Chevon Research, Richmond, GA: foamed sulfur