Very Thick Skins:
Cycling between High and Low Tech in the Sonoran Desert

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Within the boundaries of the Sonoran Desert exist a great variety of human settlements. From the electronics empires that headquarter in the swelling metropolis of Phoenix to tiny villages on Indian reservations existing without electricity or running water, the entire scale of human endeavor and full range of technology is evident. Today, many challenges to human survival are met first with a deployment of high tech solutions.

An example in the regional building industry is the use of many layers of synthetic insulation materials in combination with computer regulated air conditioning and heating units in order to maintain a comfortable interior temperature within the typically thin walled constructions of wood studs or concrete blocks. The thick walled vernacular constructions of yesteryear preserved the comfort zone with no added mechanical systems. To be appropriate, technology must be connected to the place, resources, economics, culture and the impacts of its use. Complex problems cannot be solved by using technology independent of its context. (DCAT, 1999)

This series of three case studies illustrates the cycle of high tech to low tech and back again traveled by The University of Arizona School of Architecture Design/Build program in its search for an appropriate technology with which to house desert inhabitants.

CASE STUDY 1 – MOVING FROM HIGH TO LOW TECH

The University's Athletics and Recreation Department contacted the College of Architecture in 1997 with a request for assistance with the design of a new classroom facility. The College of Architecture countered with an offer of a design/build project, and a partnership of two years duration was formed. A 4th year design studio took up the challenge to design an environmentally conscious, low cost classroom facility that could be built by novices in the construction trades (i.e., architecture students). Students and faculty spent four semesters designing, drawing, and constructing a rammed earth classroom building. In addition to the benefits of this collaboration for both the students and the client group (see endnotes), the intention to build a rammed earth structure created a need for preparation and research.

Rammed earth construction, a historical building method in the southwestern United States with positive thermal, environmental, and aesthetic attributes, faded from use in the U.S. for hundreds of years and is recently being revived as a construction alternative. (Easton, 1996) The load-bearing system requires a wall thickness of 12 to 24 inches, which may taper in section from base to top. (UBC 1997 Chpt. 71, NMAC 1411) Having almost no insulation value, rammed earth walls serve instead as thermal mass, which slows down the transfer of heat from exterior to interior spaces during the day (and performs the opposite function at night). The rate of heat transfer through a rammed earth wall is about one inch per hour. In the desert climate, this means that the sun's heat works its way towards the interior spaces, but due to the wall thickness, does not complete the transfer before nightfall. The substantial drop in air temperature at night causes the walls to cool off again before sunrise.

The possibility of gleaning most of the construction material from the site also makes rammed earth an economical and environmentally conscious choice of building construction. However, the high overhead cost of forms and scaffolding as well as the high labor investment take it out of the realm of affordability. The Design/Build studio was functioning, in essence, as building contractors with very little budget for equipment and overhead. The need to accomplish rammed earth without investing in the commercial formwork used in contemporary projects led to a research goal that would eventually affect the community beyond the campus itself.

The instigation of formwork research became the most significant aspect of this project. As the professors and the shop master in the College of Architecture worked to develop a forming system that would allow their students to construct the classroom building, the universality of their need became apparent. Contractors who focus on rammed earth construction form the entire building at once using steel reinforced concrete forms secured with steel wedges and snap ties. Employing dirt moving equipment such as bobcats and conveyers, they tamp the earth/cement mixture in a brief, intensive period with pneumatic backfill tampers. An alternative method of forming walls incrementally, with formwork that could be managed by two or three people and then reused, was necessary for low cost efforts. The efficiency of the large scale forming could be traded for the manageable system, if labor was plentiful and cheap. The research group soon realized that the problem of developing a low cost forming system for the Design/Build studio was the same as the challenge of bringing rammed earth into the affordable housing arena.

Several rounds of formwork design and test walls prefaced the Design/Build studio. The first experimental forms were based on the structure of contemporary concrete forms. Plywood sheets were reinforced with steel members and bolted together before earth tamping commenced. The unique aspect of these forms were that they could be disassembled and reassembled repeatedly to form the rammed earth walls in increments of four foot length and two foot height. The original notion was that these forms could be moved along the perimeter foundation, building up the walls in horizontal courses. The weight of the forms and difficulty of connecting the courses vertically proved to be the downfall of these experiments. The next round involved plywood reinforced by aluminum members, which were a bit lighter but still very difficult to move in the vertical axis. Tamping experiments also brought other problems to light; the forms moved under the force of the pneumatic tampers, creeping along horizontally or crawling up vertically off of the foundation. The bolted connections came under intense pressure due to the tamping and could not be loosened without damaging the hardware. Finally, a return to ancient ways of forming with planks reinforced by poles and ropes seemed to be the proper conceptual direction. (Easton, 1996) Lumber held in section against the plywood forms by pipe clamps functioned to create an assembly that could be broken down and set up quickly. The separate pieces were light enough for one person to carry and could be handed up ladders or scaffolding to complete wall sections above the first course. Using a methodology derived from examples that were a thousand years old, the Design/Build studio was ready to build.

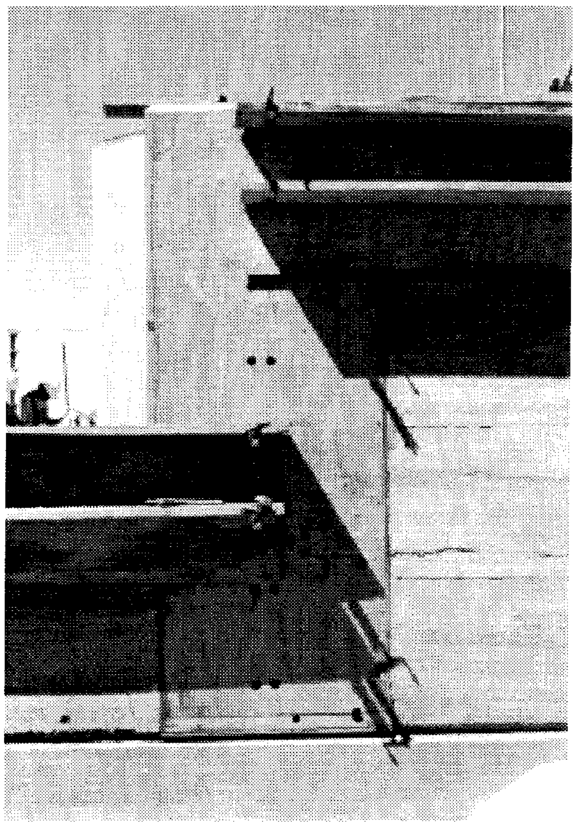

Fig. 1. Plywood and pipe clamps forms for classroom facility.

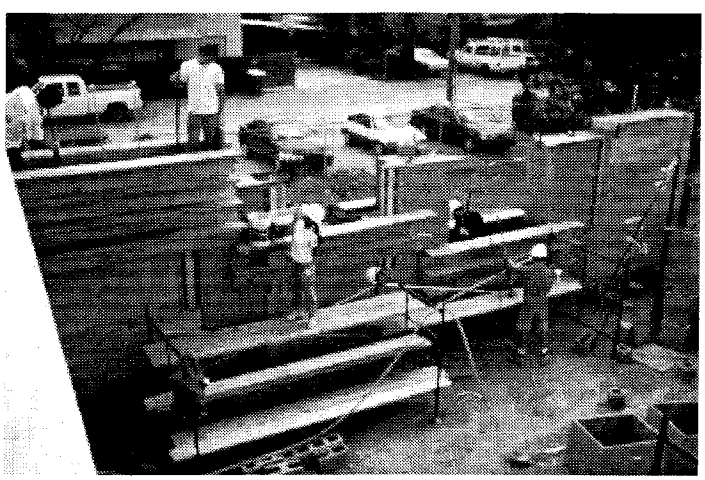

Fig. 2. Staggered wall forms system for classroom building.

As the walls rose, the forming system was rethought, revised, and constantly improved until results became consistent. The two-person system of incremental forming became a reliable system with an investment of about $300 in plywood, boards and pipe clamps. Many details added to the classroom facility, however, were observed to be time consuming. Steel angle iron screwed to the interior of forms created chamfers between the rammed earth and concrete, and bevels added to the sides of window forms shaped the apertures to spread incoming light. These aesthetic choices had a real cost in terms of labor and were later evaluated within this relationship. Within the culture of the architectural design studio, the cost of materials was of paramount importance, but the cost of labor was not. Details that consumed large amounts of student work time were considered appropriate and well worth the effort expended on them.

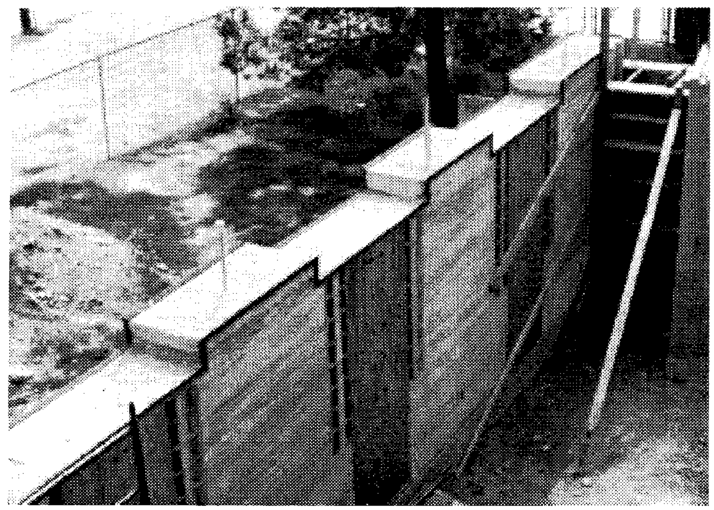

Fig. 3. Tamped rammed earth walls

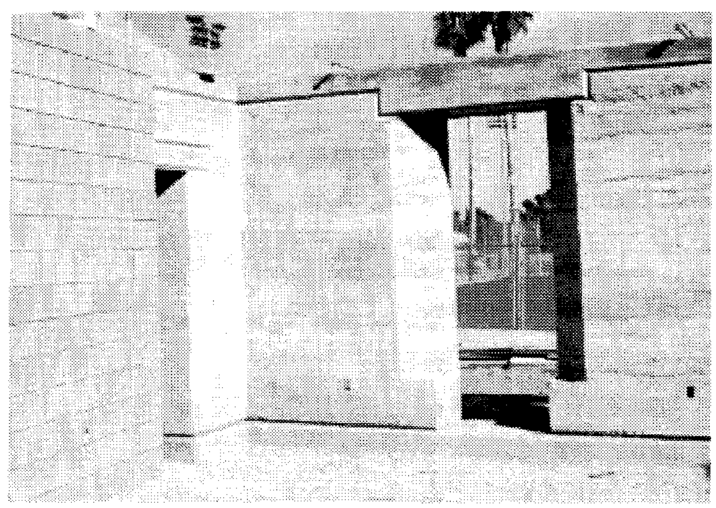

Fig. 4. Completed rammed earth walls with forms removed

CASE STUDY 2 – TECHNOLOGY FOR THE GILA RIVER COMMUNITY

Even as students shaped the classroom facility, the faculty began to realize the implications of the new forming system in the impoverished communities of the region. Research into ancient forming methods, soil composition, and wall dimensions led to speculation about a contemporary construction system that could once again be employed in the vernacular architecture of the region. One Design/Build professor wrote a grant proposal for an educational partnership between the College of Architecture and a Native American community that was in dire need of additional housing. The Gila River Indian community had rejected government built housing that bore no affinity for their traditional building methods, and most of the HUD housing had been abandoned or vandalized. The tribal Housing Committee was enthused about a partnership that would train members of the community to build rammed earth houses with a low cost system of formwork and indigenous building materials. When the grant was funded, a new collaboration was formed.

Rammed earth was originally a building technique of Native Americans of this region, as was wattle and daub. Both have been replaced in the 20th century by a composite wall system of wood and packed mud. Houses built with this system in the Gila/Pima community are referred to in English as "sandwich" houses. Most residents of the reservation live in a sandwich house, or grew up in one. While these houses require constant patching and replacement of their mud, they are valued by tenants for their maintenance of a fairly stable interior temperature in spite of the wide diurnal temperature swings of the Sonoran desert. They also hold considerable cultural value because they are a local tradition and are built by their tenants with found materials from the landscape (cactus ribs, plant stalks, earth) that remain part of the landscape when the houses deteriorate.

One major cultural icon for Native Americans in the region is the ruin of an ancient structure called "Casa Grande" today. It was a four-story watchtower or observatory built by the Hohokam tribe in the mid-1300s and became the first archeological preserve in the United States. Constructed of layers of caliche mud, the walls are 4 1/2 feet thick at the base and endure because of their mass and compaction. In 1350 AD, the Hohokam population began to decline for unknown reasons (presumably drought) and scattered into groupings of small houses once again. These communities became the Papago and Pima tribes, who lived this way until encountered by the Spanish in the 1600s. (Gregonis and Reinhard, 1979) The Pimas built of arrowweed, willow and cottonwood, which required moderate rainfall. Until the 19th century, the two most common building types were the *ki* and the *vato*. The *ki* was a slightly excavated, brush and mud covered structure with a domed adobe-plastered roof. This was used for shelter in cool weather. The *vato* was a four posted arbor covered with cactus ribs and arrowweed. This was where families cooked, ate and slept during the warmer times of the year. (Easton and Nabakov, 1989)

The later-period Pima and Papago houses were rectangular, flat-roofed structures with a post and beam frame covered with arrowweed and mud. Changes in housing practices since the 1880s have largely resulted from constant pressure by church and government groups, but the sandwich houses are not part of any government sponsored development plan and retain Pima characteristics. (Van Willigen, 1970) They include locally available materials and employ locally known techniques while evolving to reflect the arrival of milled lumber. The walls are built of mud and straw which is packed into a frame of heavy vertical posts and light horizontal cross pieces that are spaced a few inches apart or staggered. The mud fills the frame cavity and squeezes out between the cross pieces, forming a composite wall. Most sandwich houses are plastered inside and out with a coat of mud, which must be repaired frequently. The packed mud must also be repacked frequently, especially after monsoon rains wash out areas of the walls. The roofs are framed with mesquite posts, crosshatched with saguaro ribs, and thatched with arrowweed and mud. Sandwich houses are still the most common dwelling type found on the Gila River reservation and new ones are still constructed as a matter of preference and also economy.

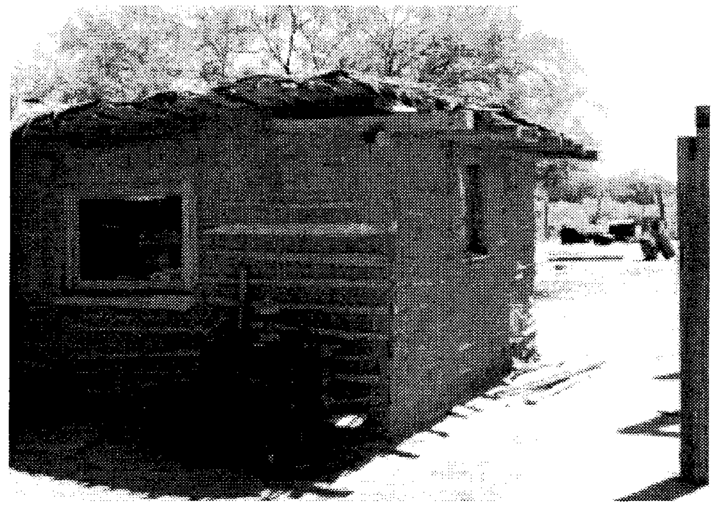

Fig. 5. Typical Gila "sandwich" house

Contemporary rammed earth techniques differ due to available technology and requirements of building codes, but the genealogy remains obvious. The reliance on the earth from the site, the intensity of the labor required, and the uncomplicated techniques involved make it an easy fit in the situation of the Gila/Pimas with their high unemployment and their housing shortage.

The professor and a new generation of Design/Build students began visiting the reservation, interviewing families, presenting housing schemes, and collecting soils samples for preliminary tests. The soil mixture had to be designed in order to make best use of the soil found on the site, and the family had preferences for integrating other traditional materials, such as cactus ribs and arrowweed thatch, into the house (see endnotes). Also, the faculty member wanted to revise the formwork to make fewer breakdown and set-up periods necessary, as those took more time and labor than the tamping. A period of design and testing followed, until the 1999 Design/Build Studio felt prepared to begin new construction.

The decision to raise the form height to four feet allowed 4x10 sheets of plywood to be used for formwork with no alterations except for drilled holes for the pipe clamps. Fewer pipe clamps were necessary with the revised formwork because the seam between forms was no longer there and did not need to be clamped on both edges. The technique of using lengths of PVC as sleeves for pipe clamps that went through the wall had been perfected during the classroom building, after experiments with lubricated pipes and tapered pipes had proven difficult. The use of wedges or shims to take the building pressure between the forms and the pipe clamps as the earth was tamped was also conceived after much trial and error during the classroom construction. All of these ideas were brought along into the next incarnation of formwork assemblage and then took on new uses in the Gila residence. One example is the use of the PVC sleeves (left inside the rammed earth walls) as conduit for the snap ties that were used to hold the plywood forms for the concrete bond beam together at the top of the rammed earth walls. The refinements and innovations that occurred throughout this process of research, design and construction could only have happened in this iterative cycle of inventing and testing.

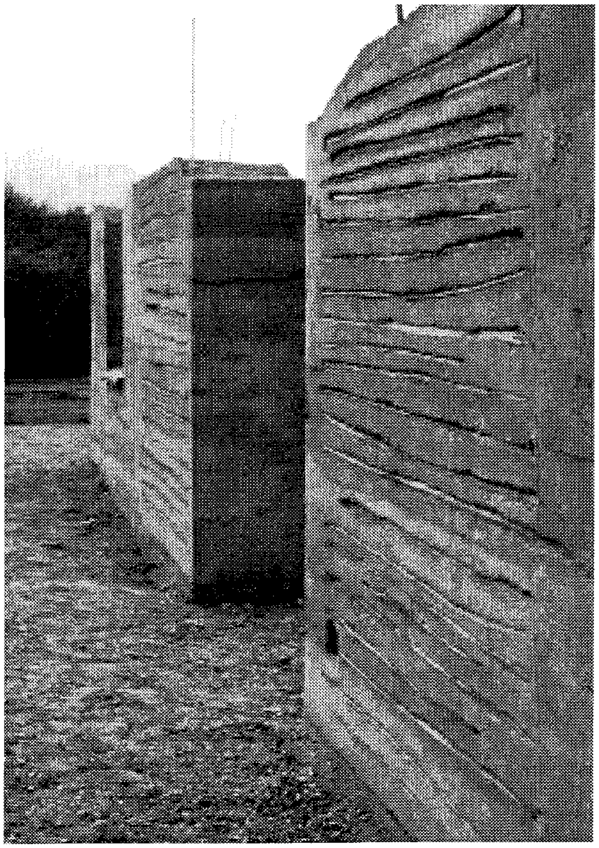

Fig. 6. Completed rammed earth walls of Gila dwelling with saguaro cactus ribs

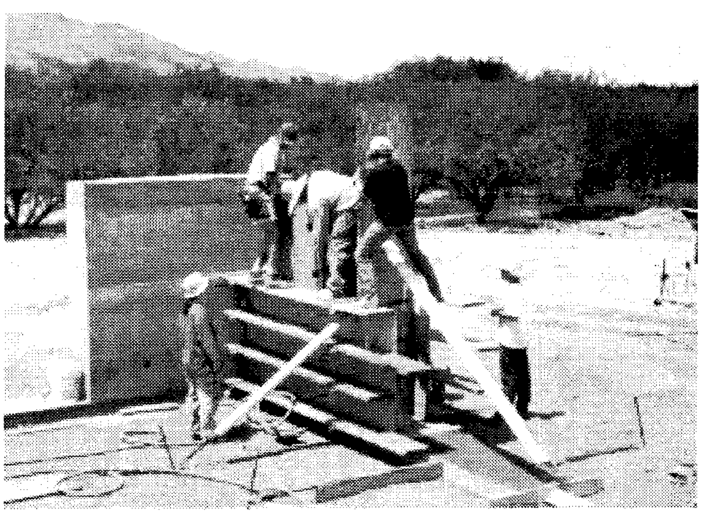

Fig. 7 Setting forms for walls of Gila dwelling

The Gila family claims that this house has some of the desirable attributes of their traditional architecture, because it maintains a constant interior temperature while using naturally available materials. The community response has been strong and more rammed earth houses are in the planning phase. Many tribe members visited the site during the construction process. They touched and slapped the walls constantly, speaking of the solidity of earthen walls and the cool temperature of the surface. Some told stories of the construction of their family homes by their extended families, and of the annual mud packing that had to be done to keep houses in good repair. Some visitors knew that the new rammed earth house stood very close to the holes left by the mesquite poles of the house built by this family's grandfather and thought it appropriate that the new house claimed the same site. Others spoke of the smell of earthen houses when it rains and thought the rammed earth would smell this way. Qualitatively, the rammed earth house appeared to be a cultural fit. In terms of technology, the lower tech, incremental formwork was appropriate for this remote site and minimal budget. The system of forming walls with two or three people and building more slowly without heavy equipment suited the logistics of the situation. The Gila construction crew fluctuates between eight and thirteen employees and they are kept busy with roof and plumbing repairs much of the time. The crew was able to spare three laborers to work steadily on the rammed earth construction, and that pace allowed for the erection of an 8x12 or 8x16 sq.ft. segment of wall each day. In this case, the chamfers and bevels created in the previous project were eliminated to save time and suit the goals of training the Gila workers in the basics of rammed earth construction. In this instance, the time consuming details were not valued as much as the straightforward logic and rhythm of the forming and tamping system.

CASE STUDY 3 – RETURN TO HIGH TECH LABORATORY

The empirical testing done by the Design/Build studio for each rammed earth project led the professor to seek interdisciplinary assistance, in order to verify hunches that were developed in the field. The observation was made that a certain percentage of clay in the soil mix was beneficial to wall strength, but less or more seemed detrimental. Also, the lore of tradesmen involved in rammed earth construction held that certain empirical methods were sufficient for judging water content in the soil mix, but experience with the Design/Build studio suggested that these judgments were not satisfactory.

A new collaboration has formed between the professor of Architecture, a professor of Civil Engineering, and a local affiliate of Habitat for Humanity. The two professors are working together (with a third crop of Design/Build students and a research assistant in Civil Engineering) to engineer a consistent earth and cement mix with consistent water content and sufficient compaction. This involves creating tests and testing equipment in the University's Soils Lab to establish the ideal soil conditions, and then experimenting to find ways of controlling field practices of rammed earth construction to achieve the same results. For example, scores of rammed earth cylinders prepared in the field were broken in the Soils Lab until a mix was derived that meets the building code requirements for compressive strength. Then, in the Soils Lab, the same mix was analyzed for water content and hydration of cement. Further tests isolated the variables of water content, cement content, hydration, and compaction energy. Once an ideal is established for each, the goal is to create an algorithm for reproducing the ideals in the actual field practice of rammed earth construction. Upcoming experiments will include translating the energy input to the miniature test lab cylinders to a time and area equation for ramming earth with pneumatic tampers in the field, as well as the use of a field kit for measuring water content of a dirt pile by noting the reaction of earth and water with a bicarbonate powder in a closed container equipped with an pressure gauge.

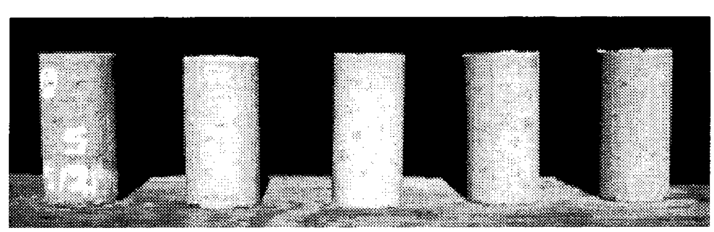

Fig. 8. Test cylinders of varying composition

The collaboration between disciplines has brought the low tech methods of rammed earth construction as practiced by the Design/Build studio back into the high tech realm for appropriate study and intervention. The Design/Build studio will employ these methods in the construction of a residence for Habitat for Humanity during the spring semester of 2001. The house has already moved through the design and drawing stages. The use of controlled laboratory studies to refine field practices is appropriate for a collaboration between the university and the community it serves. While more time efficient forming systems have been deliberately avoided to control costs, more specific recipes for soil-cement and better hydration and compaction practices may affect costs as well. The new field practices will use the technology and sophisticated testing methods of the laboratory to influence a building technology that is deliberately kept in the realm of hand craftsmanship.

These three projects illustrate a cycle that fluctuates between high and low technology, adjusting to the climate, culture, resources, environmental concerns, and economics in order to find a level of technology that is appropriate to this place and time.

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NMAC, Construction Industries Division of the Regulating and Licensing Department of the State of New Mexico, Appendix 1411.

Uniform Building Code, 1997, Chapter 71.

ENDNOTES

Case Study 1

This collaboration in itself produced benefits for both the students of architecture and the client group. Students participated in many activities that foreshadowed their professional careers, from client meetings to programming exercises, code checks, and budget reviews. Another type of learning took place once the construction phase began. Students organized and placed materials orders, met deliveries, and practiced skills such as welding, carpentry, and earth tamping. Carefully dimensioned sketches filled notebooks as students planned and prepared for each day's exertions. They became more confident with solving construction problems in the field, trying innovative solutions, imagining how materials assemblies come together, drawing their ideas in sketchbooks, and relying upon their intuition about physical problems. The impact on their design thinking was immediate and tangible. The Recreation Department received, in the words of its Director, "Much, much more than the metal shed we would have settled for".

Case Study 2

Once again, evidence appeared to suggest that blue-collar capability had broadened white-collar tradition in the design studio. Hart framing hammers appeared beside the Maylines, and steel-toed boots replaced the Doc Martins. Many students claimed that, although they had previously traced or copied working drawing sections for residential construction, they had never before paid attention to or understood the assemblies of materials. Most of the students claimed that a true enjoyment of making tangible objects compelled them to take the course, as well as a desire to learn about construction methods and gain field experience that would lend them credibility in construction administration roles in their future careers. Several cited the opportunity for fresh air and exercise as a reason to contribute more weekends of labor than were required for course credit; a few noted the satisfaction derived from time spent in altruistic pursuits. All of the students who gave written responses on the course evaluation forms at the end of the semester claimed to have learned a great deal about how to make buildings and to have experienced a shift in design priorities that recognized the making of architecture as a consideration in the preliminary process rather than as an afterthought.

For some students, the contact with the actual users of the project proved to be the most confusing and complex aspect of the course. While building techniques could be clarified by drawing and demonstration, clients' opinions and attitudes were often rendered opaque by differences in education and ethnicity. The students believed themselves to be in possession of rare and important architectural knowledge, imbued by their professional training and expanded by their recent collections of construction tools and jargon. The usual perceptions of experts vs. novices were reversed when some tribe members showed facility with construction practices yet unknown to the college students. Once this acknowledgement occurred, students still had trouble giving credence to the clients' viewpoints in matters of aesthetics. Long debates ensued after the clients requested the addition of saguaro ribs to the rammed earth walls, for the purpose of ornament. Students believed that because the ribs were not structural, their use was superfluous. It took a number of lunches at the traditional home of the client family to soften their point of view and allow them to realize that arguments about architectural purity had little credence in this context.

The Gila family has a strong affection for their present home, although it is very small and in poor repair. They do not wish to see it razed by the tribal Housing Authority, and hope to keep it on as a storage building or guest quarters. It is over 70 years old and was built by the late grandfather of the family. The appearance of the mud and saguaro rib walls is a desirable attribute for this family, who asked for a similar appearance in some location of their new home. The challenge to incorporate saguaro ribs into the formwork and earth tamping system of rammed earth led to several experiments with strips of milled lumber and cactus ribs and different methods of embedding them into the earth or attaching them to the formwork. The goal was to leave one face of the cactus ribs revealed once the forms were removed. Initial attempts to tie strips and ribs into forms using hemp or wire failed, as did efforts to create a reveal in the surface of the rammed earth with ribs exposed behind it. The desired end result was finally accomplished by laying the ribs against the formwork one by one as the tamping progressed, anchoring them into the rammed earth with 3-inch drywall screws, and brushing them with a wire brush to subtract the covering surface once the forms were removed. The saguaro ribs could not extend the full length of the forms because the ends would then be exposed and eventually pull free from the wall mass. The decision was made to set the ribs in 12 inches from the end of the form, which also allowed the visual understanding that they served an ornamental rather than structural purpose.

Case Study 3

The workshop leading up to the construction of the third rammed earth building was valuable for its lessons about the rigorous nature of laboratory research. Architecture students struggled with the logistics of controlled testing when only one variable at a time was allowed. They ruined several batches of test cylinder data by marking the cylinders in ways that were destroyed by the compression tests. They ruined another batch of data by improperly calculating the percentage of cement content. Students did not at first understand the importance of graphing stress and strain for all cylinders using the same increments of time and load on their charts. Other experiments with pigment added to the soil-cement mixture and subtractions made from the rammed earth by adding pieces to the formwork began in very arbitrary ways and eventually found focus. The necessity of a hypothesis, consistent quantitative measures, control samples, etc. were new working methods for architecture students.