THE AVENUE OF IDEAS: A SUSTAINABLE, AFFORDABLE HOUSING EXPERIMENT

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INTRODUCTION

The metropolitan area of Tucson, Arizona is a repository of traditions for dwelling in extreme conditions, as well as an incubator for new ideas about desert architecture. It is also a place with a long history of poverty and struggle for existence against harsh natural elements.

With these conditions in mind, the City of Tucson partnered with five non-profit housing providers to build on one avenue an array of affordable housing prototypes that demonstrate to the public a variety of building systems that work to stabilize interiors from the diurnal temperature swings through insulation or thermal mass. Beginning in 1997, local non-profit housing providers designed and constructed sixteen residences representing five different methods of building low cost housing that comfortably mitigates the summer heat and winter chill. The last of the residences was completed in 2003; all are currently inhabited and in constant use. This article proposes a comparison of the environmental control strategies, building methods, costs, and energy usage of the five different systems as they were brought to fruition in the sixteen residences.

Included in the construction methods are: insulated concrete block, foam blocks with concrete-filled cavities, light-gauge steel framing with foam block infill panels, straw bales, and rammed earth. The first four types use insulation as the means of stabilizing interior comforts while the last method relies upon thermal mass. The residences each enclose between 1000 and 1150 square feet of conditioned space and have similar solar orientations. Additionally, each of the homes was inspected during construction by the Tucson Electric Power Company and is guaranteed to provide comfort at a specific monthly cost. The site planning for the sixteen parcels conserves a natural drainage swale as an unbuildable area and promotes roof water collection and retention. A plant survey identified significant native species, which were tagged and protected during construction.

Platted as a sixteen-parcel subdivision, this avenue of experimental residences aims to demonstrate to the citizens of a rapidly growing metropolis some of the possibilities for living within their means while adhering to an ethical stance regarding the local and global environment.

1. CATALYSTS

1.1. Two Houses

The City of Tucson Community Services Department (CSD) received a grant from the U.S. Department of Energy in 1996 to build two straw bale houses on a city owned parcel of land in a low-income neighborhood of Tucson. The City partnered with two local non-profit housing providers to design and construct the dwellings as an experiment in low cost, energy efficient housing. Built by the Tucson Urban League and Habitat for Humanity Tucson, these small houses were catalysts for community action and interest toward affordable housing with low energy costs. Built in 1997, the houses reportedly use $30 worth of electricity each month. This compares to a median electric bill of $70 (1) per month in Tucson.

1.2. A Request for Proposals

The City CSD soon followed this effort with a site planning charrette to design the layout for 16 additional parcels adjacent to the two straw bale houses. Community members and professionals participated in the session to design a water run-off system integrated with a natural drainage swale on the site, and to identify significant native plants that would be tagged and protected during construction.

In 2000, the City of Tucson issued a Request for Proposals to non-profit housing providers to develop the 16 parcels of Banks Grove Subdivision as an *af-*

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FIGURE 1. Aerial view of Banks Grove subdivision.

FIGURE 2. Integra Block residence under construction.

fordable, sustainable homeownership project. The infrastructure of sewer lines, street, and sidewalks was provided by the City of Tucson.

The CSD put forward the following criteria for the affordable, sustainable single-family dwellings to be constructed in the subdivision:

- Units should have minimum of 3 bedrooms and 2 baths (approx. 1100 sq.ft.)
- Energy efficiency to meet the Civano Standard (2) (50% reduction in energy costs over the Model Energy Code of R38 roof, R19 walls, low-E double-paned windows U0.32, minimum SEER 13 air conditioning systems, strategies for window orientation, percentage of window to wall, etc.)
- Use of alternative technologies (straw bale, rammed earth, integra block, rastra block, foam systems, etc.)
- "Visitability" to all units (3′–0″ doors)
- Metal roofs
- Ground mounted mechanical systems
- On-site water harvesting

2. INTEGRA BLOCK

Primavera Builders constructed four dwellings of Integra Block, a foam-insulated concrete block. This load bearing wall system uses a post-tensioned rein-

FIGURE 3. Floor plan of Integra Block residence.

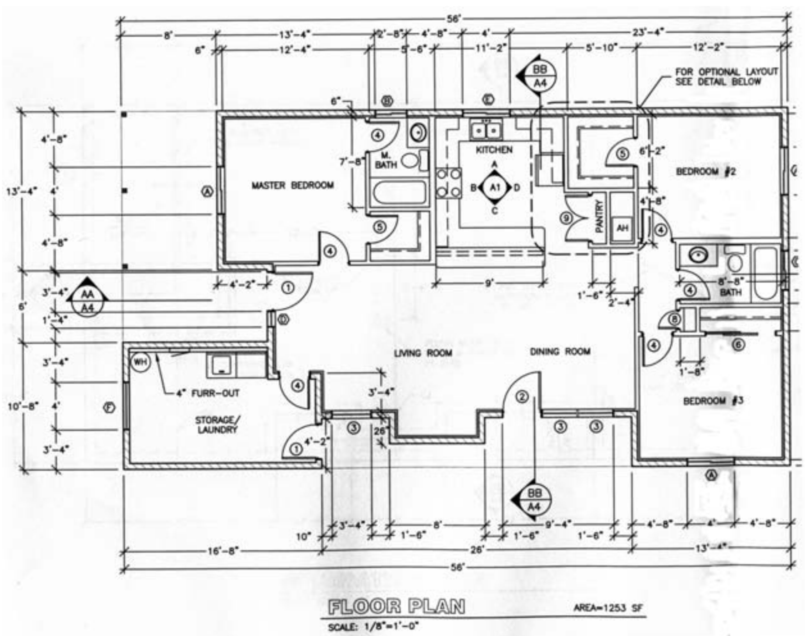
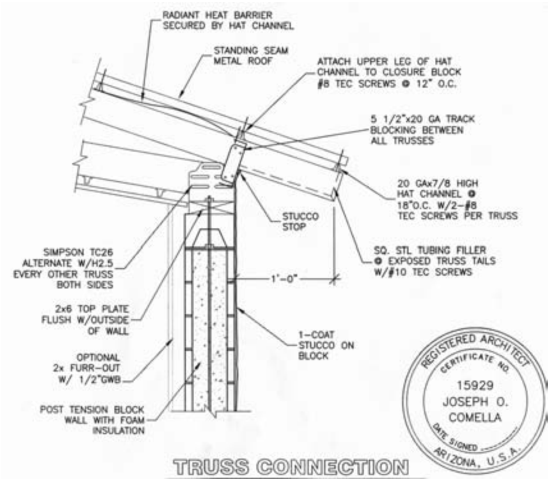
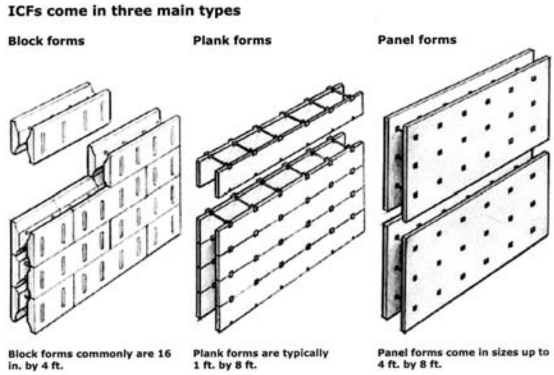


FIGURE 4. Wall section of Integra Block residence.



forcing system that resists flexural cracking and allows much of the wall to be reinforced without the use of grout. With less grout and less web material, much of the thermal bridging is thus reduced, and the cavities of the blocks are filled with pressurized polyurethane foam. R-values of 27 are possible with 12″ block and good construction practices (3). The exterior of the residences were finished with cementitious stucco, and the interior walls were plastered. A recent field study by Chalfoun and Michal, however, reported that poor workmanship and improper solar orientation significantly reduces the effective R-value of Integra block walls (4). Further inquiries into this field study revealed that the Integra block was a special 4″ slump block, made to look like adobe, which had four times the thermal bridging of normal Integra block, thus negatively affecting the results.

FIGURE 5. Types of ICF systems.



3. ICF SYSTEM

Tucson Metropolitan Ministries constructed four dwellings of an ICF (insulating concrete form) system known as "Blue Maxx." All ICF systems consist of expanded polystyrene forms filled with concrete, resulting in a combination of thermal mass and insulation.

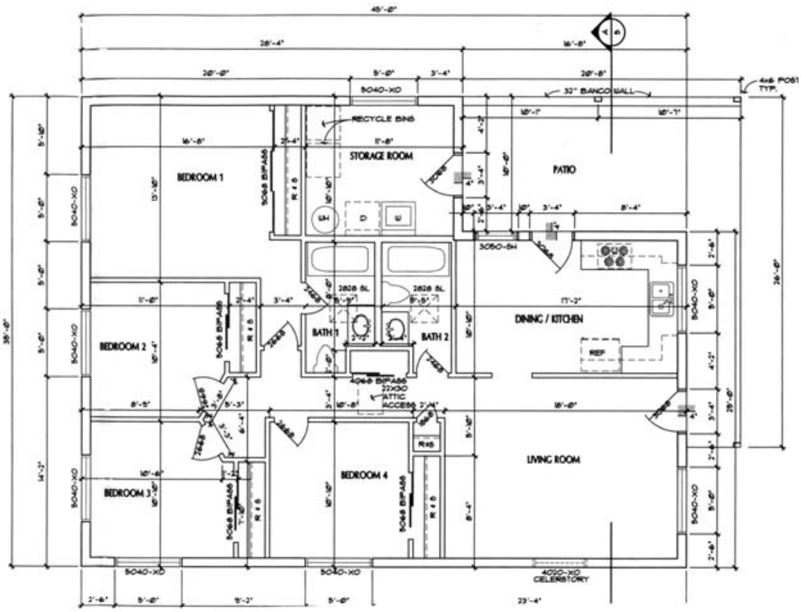
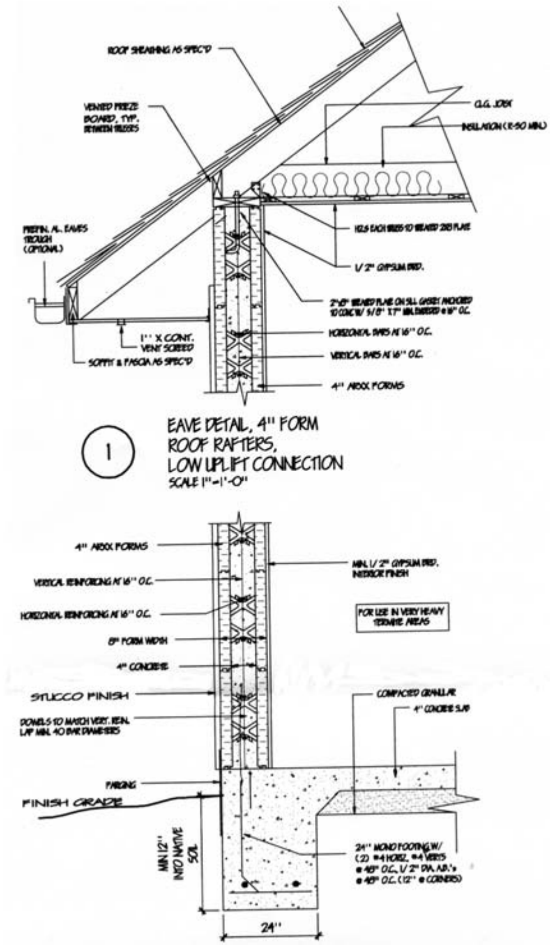


FIGURE 6. Floor plan of ICF system residence.

FIGURE 7. Wall section of ICF system residence.



These systems are accorded an R22 thermal resistance factor when constructed in conformation with procedures in the ASHRAE Handbook 1997. Manufacturers argue that the thermal performance of the systems can exceed the performance of a wood framed wall insulated up to R50 (5).

There are three main types of ICF forms: blocks, planks, and panels. Blocks are the most common, consisting of expanded polystyrene sides held together with plastic or steel connectors that extend through to the face of the block to provide a fastening point for wall finishes. Plank forms are similar, but longer and narrower, while panel forms can be as large as 4 ft. by 8 ft. The three form types shape the concrete within in one of three ways: flat wall, grid wall, or post and beam. All require reinforcing steel, and have differing structural capacities and susceptibility to voids within the concrete portions. The walls are covered with a cementitious plaster inside and out.

Blue Maxx is a block system that uses plastic fasteners that serve as cross-bracing and also seats for the reinforcing steel. The builder of the Blue Maxx residences reported high satisfaction with the product because of the pre-engineering and ease of assembly. His only complaint was that the walls are braced from the interior floor slab as they are constructed, and the bracing was destructive to the finished concrete floor. Blue Maxx walls release minimal VOCs (Volatile Organic Compounds) and no CFCs, HCFCs, or Formaldehyde. There are no thermal bridges within the system, and no air infiltration due to the complete integration of the concrete and polystyrene. The manufacturers of the system product claim an energy savings of up to 70% per year in utilities, but this has not been verified in the Banks Grove development.

4. HEYDON SYSTEM

Heydon Builders constructed six residences using the Heydon Building System, an integration of light gauge steel framing with four-inch polystyrene panels that interlock with the studs. The complete envelopment of the steel studs by polystyrene eliminates thermal bridging, and the manufacturers claim an R value of 25 for this system when plastered on both sides with cementitious stucco. Recent improvements in the Heydon system have moved the polystyrene completely to the exterior of the steel framing, with no penetrating fasteners. Additionally, the manufacturers have developed a polystyrene envelope for the steel roof trusses so that the entire struc-

FIGURE 8. Heydon System walls under construction.

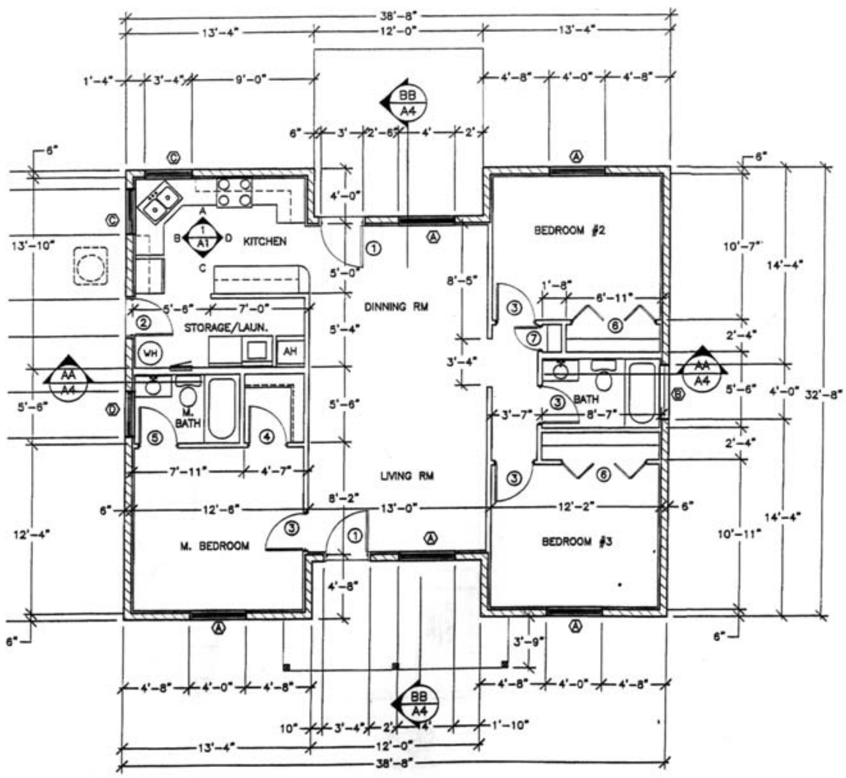
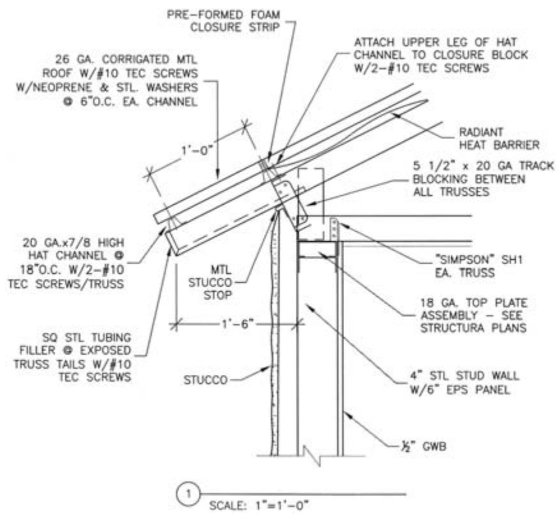


FIGURE 9. Floor plan of Heydon System residence.

ture is insulated. The heating and cooling ducts are therefore brought into the interior of the conditioned space, removing a significant source of heating and cooling loss. Exterior walls are covered with cementitious stucco, but can alternatively be finished with metal siding or any other sheet material. A recent study of construction techniques in Tucson (4) ascribed an R-value of 25 to the Heydon System. Of the five systems studied (Integra block, Heydon System, adobe block, SIPS panels, and straw bales), the Heydon System had the lowest energy cost (.23 USD) per square foot. The actual utilities costs of the Heydon System homes in the Banks Grove subdivision have yet to be verified.

FIGURE 10. Heydon System Section.



5. STRAW BALE

The University of Arizona School of Architecture's Design-Build Studio partnered with Habitat for Humanity Tucson to build a third straw bale house for the subdivision. The students and faculty involved in the project designed and constructed a post and beam structural system with straw bales used as infill wall

FIGURE 11. Straw bale residence under construction.

material. The main vertical members (box columns) were constructed of 4×4 and 2×4 wood sheathed with oriented strand board (a recycled wood product) and insulated with packed straw. These members created the apertures for doors and windows framed into the walls, and supported the perimeter roof beam. Framed portions of the house (above and below windows) were insulated with fiberglass batt insulation and carefully shaded to protect the windows and doors from direct solar gain. Other passive solar strategies were

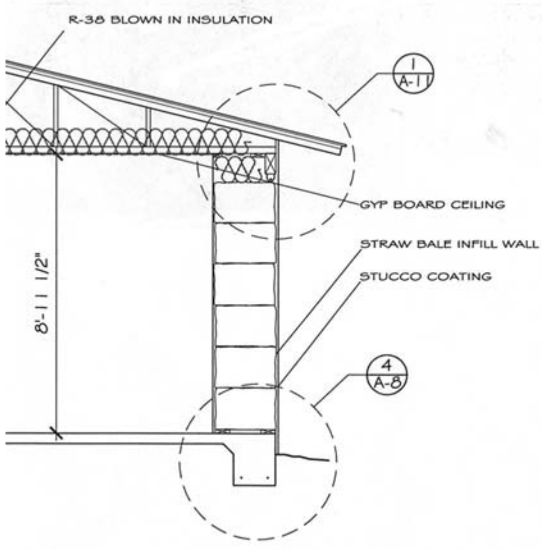


FIGURE 13. Wall section of straw bale residence.

used in the site planning of the dwelling: windows and doors were oriented to the north and south, where they could be protected from unwanted solar gain, outdoor open spaces were also oriented to the north and south and shaded by the roof. Long walls of straw bales are exposed to the direct sun on the east and west

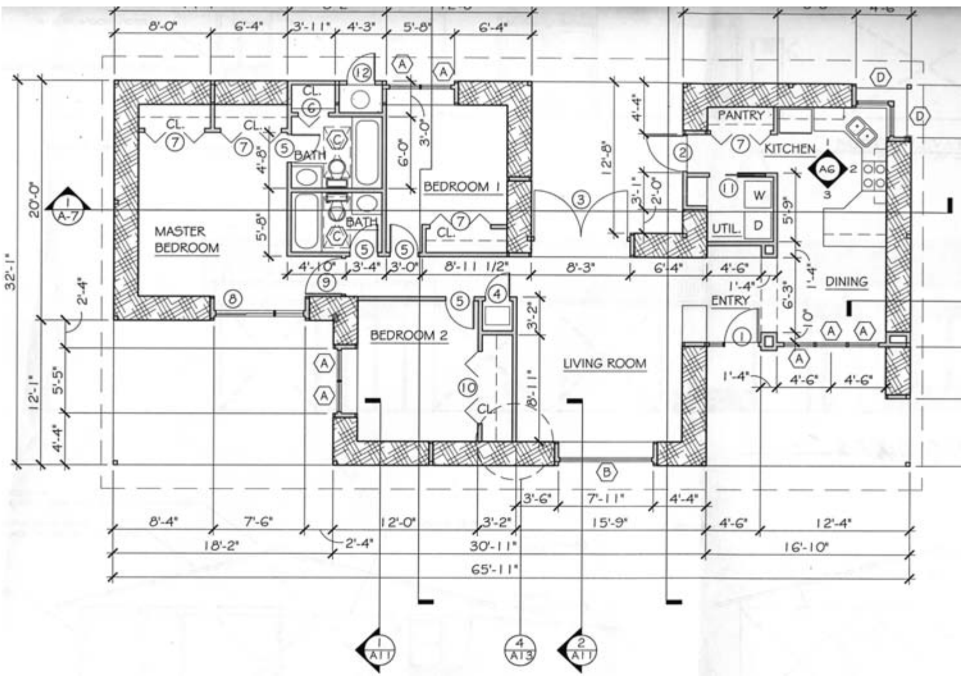


FIGURE 12. Floor plan of straw bale residence.

FIGURE 14. Completed straw bale residence with roof overhang to shade south windows.

FIGURE 15. Rammed earth residence under construction.

sides, where their insulating value is most useful. Early thermal testing (1993) indicated that straw bale assemblies could achieve a thermal resistance value of R48 (6), but this has been reduced to R27 (7) by more current testing laboratories.

The straw used in the insulating walls is an agricultural waste product, and requires no special treatment except to be carefully plastered to protect it from moisture. The oriented strand board uses phenol-formaldehyde adhesive that is less toxic than urea-formaldehyde and does not produce significant off-gas. The aforementioned comparative study (4) rated straw bale construction just under the Heydon System in terms of energy costs (.25 USD) per square foot.

6. RAMMED EARTH

The University of Arizona School of Architecture's Design-Build Studio partnered with Habitat for Humanity Tucson to build a rammed earth residence on

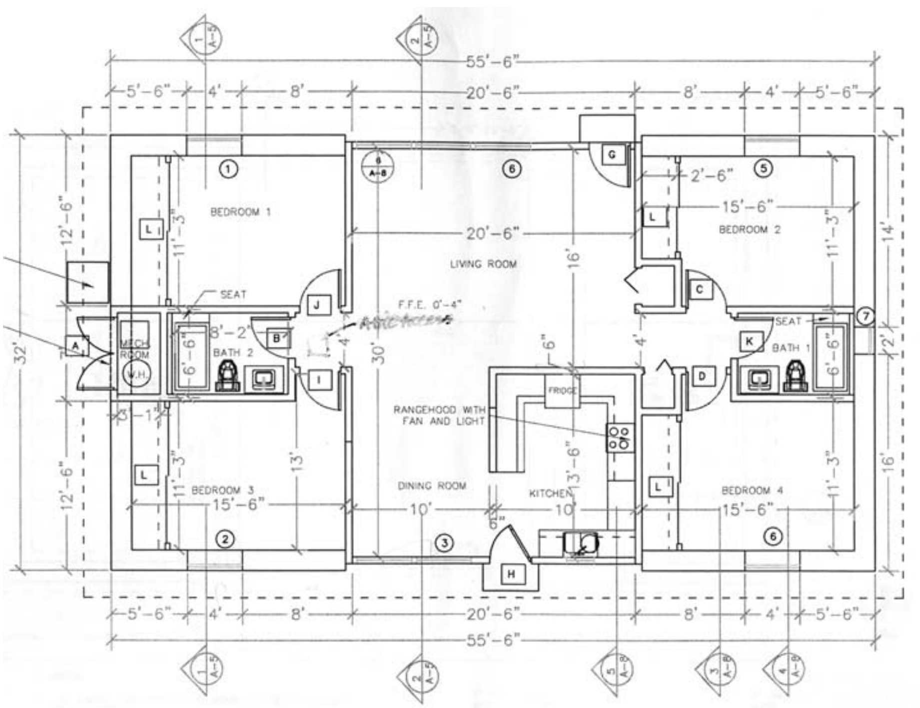
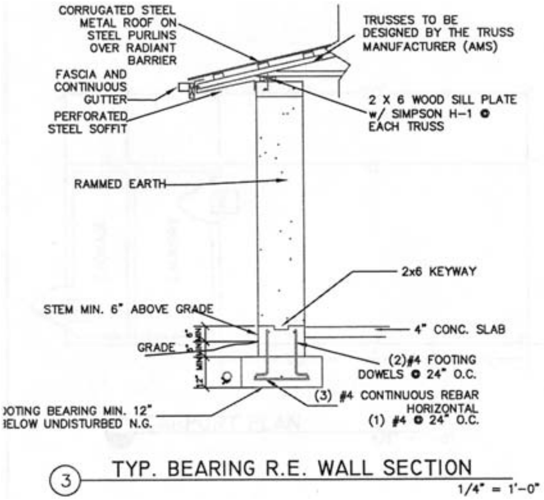


FIGURE 16. Floor plan of rammed earth residence.

FIGURE 17. Wall section of rammed earth residence.



one parcel of the subdivision. The students and faculty involved designed and constructed load-bearing rammed earth walls separated by light gauge steel framed walls holding most of the doors and windows.

The load-bearing system requires wall thicknesses of 12 to 24 inches that may taper in section from base to top. 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. In Tucson, the ideal wall thickness is 16 inches or more, due to the length of the days in summer. 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.

FIGURE 18. Completed rammed earth residence with roof overhangs to shade south windows.

Rammed earth was originally a building technique of Native Americans of this region, as was wattle and daub. Both have been replaced in this century by a composite wall system of wood and packed mud. While these houses require constant patching and replacement of the 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.

While contemporary rammed earth techniques differ due to available technology and requirements of building codes, 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 arid regions of the southwest, with their housing shortages and ready supplies of unskilled labor. Rammed-earth construction faded from use in the U.S. for hundreds of years and is recently being revived as an alternative for custom homes. Since the mid-1990s rammed earth construction has undergone a renaissance in the southwestern states, primarily in California and Arizona. Contemporary construction methods for rammed-earth employ the stabilizing additive of Portland cement, pneumatic backfill tampers to compact the earth mix, and forms fabricated for cast-in-place concrete construction.

The rammed earth walls for the Banks Grove residence were oriented mainly to the east and west, where their 18-inch thickness could serve as a thermal mass to offset the heat from direct sunlight coming from those directions. Some rammed earth was used on the north and south sides, but much of the wall with those exposures was framed and insulated because those were the best exposures for windows and doors. The northern exposure receives very little direct sun, while roof overhangs can effectively shade the southern exposure. Two improvements could be made to the construction of the rammed earth residence in order to enhance energy savings: insulation of the perimeter of the slab would reduce heat gain and loss, and the reduction of some of the shade on the southern exposure would allow winter solar gain through the windows onto the exposed concrete floor.

7. CONCLUSIONS

While the individual merits of the construction systems on Banks Grove Place are laudable, siting decisions and workmanship on individual residences most likely mitigate ideal results. Careful attention to the solar orientation of windows and walls enhances the thermal performance of the rammed earth and straw bale residences. The benefits gained from the high thermal mass or high insulation are not squandered by poor orientation of windows and doors. The longest, uninterrupted stretches of insulated walls or thermal mass walls are turned towards the most brutal exposures. Careful placement of carports and outbuildings augment the shading strategies for vulnerable walls and glazing.

Of the other residences, some examples of each system are oriented for maximum passive solar protection or gain, but others are turned to face the curving street without regard for the east and west facing glass. Site planning could be better managed to ensure that each unit takes maximum advantage of passive solar strategies.

Metal roofs with radiant barriers are good choices for low-cost housing as well as housing of any other budget strata. The metal panels are cut to length on site, with no waste, and are warranted for 40 years of service. The metal sheds water easily and fascia details are compatible with gutters to carry water to downspouts and oasis landscape areas, cisterns, or drainage swales existing on the site. All air conditioning and heating units are ground mounted rather than roof mounted, thus allowing better maintenance and screening from the sun.

Landscaping for all sixteen residences was minimal, but adhered to principles of "xeriscape" design: low water use plants, native species, conservation of existing plants, and mulching of surface area with moisture conserving materials (in this case decomposed granite). Rainwater run-off was directed back to an existing swale, which was reinforced for continuation under the street and back to its natural course through the area toward the Santa Cruz River.

Further study would quantify the thermal performance of the building envelopes employed in the subdivision, as well as the actual energy use of the owner families. It is appropriate to assume that the results of the Chalfoun and Michal study would apply here—with ideal results compromised in some ways by poor workmanship or design decisions. The ICF system and rammed earth were not part of that study, however, and a similar use of computer modeling and field testing would add more comparative data to a body of knowledge about construction systems in the arid regions of the southwestern U.S.

In summary, the Banks Grove Place subdivision was a remarkable effort for a small city with a large number of low-income citizens. The intention to model various types of construction that can be achieved for a low initial cost but offer substantial savings in energy costs is admirable in communities of any scale. The fact that the city's Community Development Services platted the land, provided the infrastructure, sent out the request for proposals, and then provided technical assistance with construction documents to several of the non-profits is a testament to the level of commitment in this progressive metropolis.

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