

Low-Tech Building: Innovations and Lessons Learned

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INTRODUCTION

In May of 1994 my wife Jennie and I began constructing with our own labor a 3,400-square-foot home for ourselves. I designed the two-story house which is on a sloping site and includes a two-story space, 18-foot spans, a crawl space, an attic, an interior courtyard open to the sky, a four-story tower, a 24-foot bridge, a cantilevered balcony, two raised decks, an 8/12 sloped roof, and a masonry chimney. The construction is light-gauge steel framing combined with a concrete block weathering surface forming 16-inch thick walls. The two of

us are performing virtually all the work including the foundation, structure, enclosure, ductwork, electrical system, and plumbing. We are fabricating the 73 windows. No cranes or lifts are being used. Materials and overhead will total about \$30 per square foot. The work is in the third year of a four-year schedule with occupancy of the first floor anticipated at the end of this year. At this time the foundation, first floor plumbing, first floor duct system, and half the framing are complete, having passed the various city inspections. Some rafters are in place.

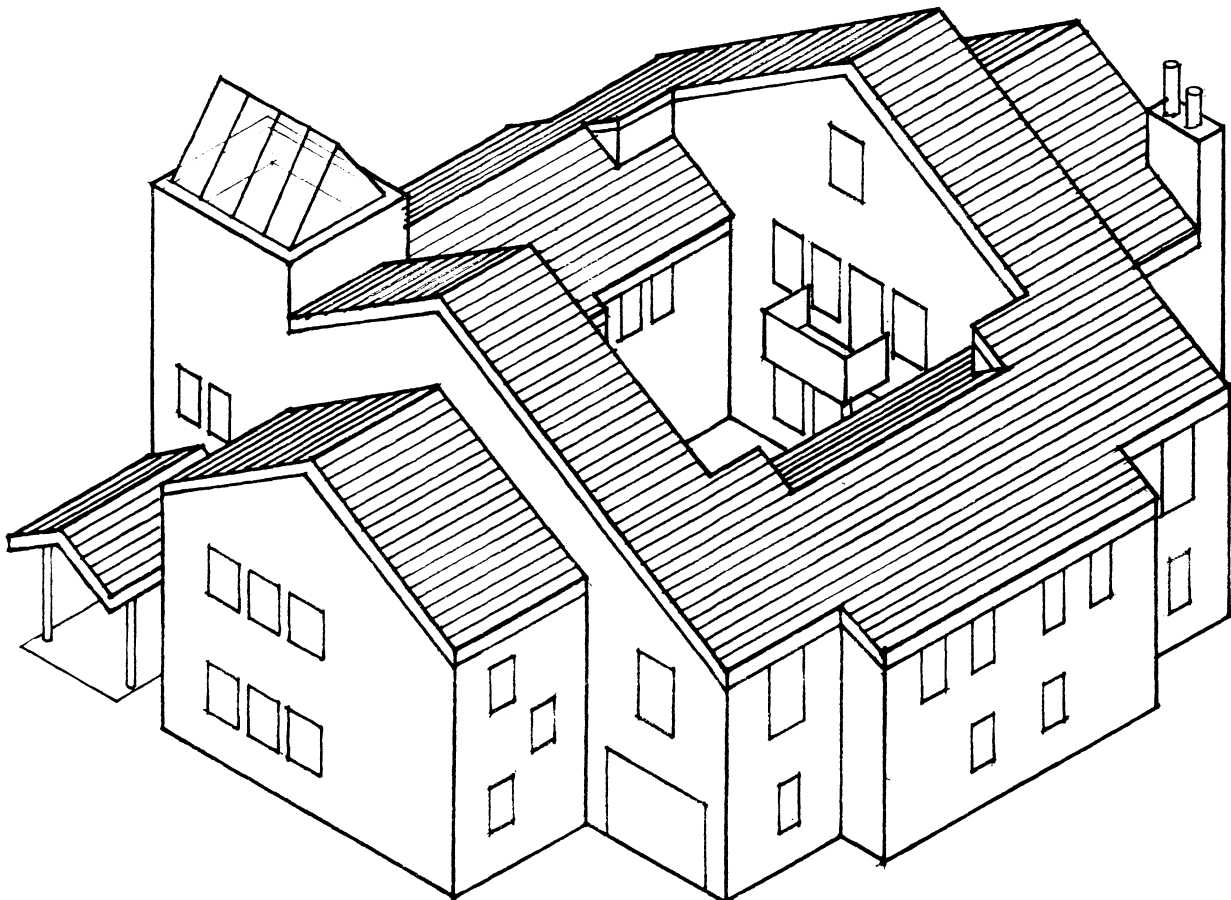


Fig. 1. The house from the northeast.

As an architect I understand construction from a theoretical and observers point of view having had office experience before entering academia. When we began the project, however, neither my wife nor I were skilled in construction practices nor do we have access to the larger equipment typically used in house construction. The size and complexity of the work, the materials used, our lack of equipment, and the limitations of our skills have generated thus far a construction experience replete with lessons as well as a few innovations which may be of interest to teachers and to builders both amateur and professional.

PREPARATIONS

Prior to breaking ground I ordered \$1250 worth of borings to determine the bearing capacity of the soil. This is not common for home building in our area but in the absence of experience that might dictate otherwise, I intended to adhere to theoretically correct practices. I gave the soil testing company dimensioned locations of three boring holes and my wife met them at the site to observe the process. When she saw that they intended to drill without measurements she insisted that they locate the boring positions with a tape. After two holes were drilled she left the site and apparently so did the drilling crew. It seems that they never drilled the third hole that we had paid for. When digging the footing we found the two borings my wife witnessed but could not locate the third. The data in the soils report for the second and third hole were identical, an unusual coincidence. In addition the depth of the bed rock at the third hole turned out to be 18 inches deeper than the report indicated. Having no real proof we did not initiate legal action against the company. It appears that amateur builders without having the clout of offering return business and by seeming to be naive are especially vulnerable to this kind of dishonesty.

Due to our inexperience we made a poor decision in our first tool purchase. To save money we bought a site-level instead of a transit. The inability of the level to rotate on a vertical line plagued us throughout the layout of the foundation on the sloping grade. Learning to survey at this simple extent was relatively easy being an exercise dependent more on logic than experience. The inexpensive instrument was not dependable enough to establish right-angled corners without measured verification which slowed the work. Our survey, nevertheless, turned out to be accurate enough for us to correct the few minor errors we found during subsequent construction. The lack of transit capabilities affected the work again when we were unable to monitor the trueness of our framed walls during their erection with more than a 4-foot spirit-level. We were unable to routinely use a plumb bob due to the frequent wind. Eventually we were forced to align the rafter overhangs with the foundation so that the block wall to be built later would pass just behind the fascia. To do this we lowered a 12-ounce plumb bob 22 feet into a can of water (to reduce its sway).

THE FOUNDATION

The expectation of shallow bedrock encouraged us to use a foundation wall on a spread footing although houses in our neighborhood are on grade beams and piers. When a heavy equipment operator we knew could not dig our footing trenches, our excessive enthusiasm, our suspicion of subcontractors, and the inaccurate soils report lead us into an ill-advised decision. With bedrock thought to be only 30 inches deep in the sandy soil, we preferred to dig the 32-inch-wide trenches ourselves rather than begin the search for a new subcontractor. The two of us began digging 460 feet of footing trenches with shovels.

The width of the footing is twice the width of the 16-inch stem-wall which is unnecessary for bearing purposes but relatively narrow in which to build formwork. After two weeks of hand-digging we gave up having been consumed by poison ivy. The cost of medical attention had become significant while Jennie's hands and my knees were nearly inoperable. We had completed half the trenches. Jennie then selected a particular back-hoe operator because, among those she called, he was the most civil. Since some men in the building industry had been either patronizing or hostile toward her we intended to give business to the least sexist subcontractors and suppliers. (Eventually we had to abandon this policy due to the small number of choices that it afforded us.) This back-hoe contractor was entirely satisfactory and dug the other half of our footings in one day for \$360.

We spent several weeks bending and placing 3000 feet of 1/2-inch steel reinforcing rods for the footings. My wife assembled the steel in the trenches while I used two pipes to bend the rods between a tree and a tripod of steel fence posts. Once we were ready for concrete Jennie could not find a ready-mix company that would quote her a reasonable price. I called and was quoted a cubic-yard price \$30 less than was given to her. We realized at that point that she was not going to be able to handle all the pricing due to the attitude of some vendors toward women.

Since our sandy soil would prevent ready-mix trucks from leaving the gravel drive we decided to pump the concrete across our site. To avoid the cost of a boom-truck to carry the pump hose, I decided to move it by hand. Then in what might be the biggest mistake of the project, I ordered a 4-inch diameter hose to be used. The pump contractor tried to talk me into using a 2-1/2-inch hose but I would not listen since I wanted to maximize the size of the aggregate. Since every 6 feet of a 4-inch hose filled with concrete weighs nearly 100 pounds, we decided to hire six students to assist us. When we were unable to afford workmen's compensation insurance for the student crew we canceled the plan to use help. The insurance carried a \$720 minimum fee which would increase in proportion to the annual payroll. We were not planning to have an annual payroll large enough to justify the minimum cost.

The footings required 64 cubic yards of concrete which arrived in eight trucks spaced over the afternoon. Jennie and

I could not move the hose quickly enough to keep up with the pumping. Shortly after we began the struggle it was clear to everyone that a disaster was in the making. The president of the ready-mix company arrived and offered assistance after a driver called him on a truck radio. Soon he was directing his drivers to help in various ways, a remarkable act of generosity as it is not their job to place the concrete. In spite of the fact that it was not his job either, the pump driver disconnected, emptied, reassembled, and helped drag the hose back and forth for three hours as we placed concrete in the foundation footprint. We expressed our gratitude by tipping the ready-mix president \$560 and the pump driver \$100 beyond the cost of their basic services. The difficult experience was to affect the next phase of the work and lead to our first construction innovation.

Since we did not have the skill to pour a concrete wall suitable for exposure to view, I designed the foundation wall as a composite with concrete below grade and concrete block above. We held the top of the block to just above grade on the lower side of the house and subsequently brought the foundation wall up to floor level with steel framing to save the time of laying the additional concrete block. Consequently the top of the concrete wall had to step down the slope of the site in 8-inch increments (to receive the concrete block) while its base sloped with the top of the footing. We used treated 2-by-6-inch lumber for the formwork as we intended to reuse the wood in the floor of scaffolding and eventually on the surface of a large deck. In order to maximize the reuse of the lumber we minimized cutting it to fit the needs of the stem-wall. We began forming the stem-wall by securing the top 2-by-6 in a level position and enclosing the space below it by lapping the lumber over each other in a kind of partially opened fan shape. Much of the formwork, therefore, had a stepped surface as each lower 2-by-6 was set outside the one above. In this way none would have to be cut to fit into the irregular gap between the top lumber and the sloped surface of the footing. The first stem-wall sections had the appearance of a sort of ziggurat, being wider at the base and stepping inward to the narrower top.

When we realized that our formwork was not strong enough to survive the repetitive impact of pumped concrete, we decided to mix and place the concrete ourselves. We bought a 3 cubic-foot electric concrete mixer for \$260. We mixed and placed 24 cubic yards of concrete into the stem-wall in lifts of 1-1/2 cubic feet as this was all the mixer could hold without spilling. We had not been worried about the extra concrete necessary to fill the spread-base of the stem-wall when we were planning to use ready-mix. Since we were mixing and placing by hand, however, we became sensitive to the large amount of extra concrete and the time needed to place it in the widened base. Because we were building only enough formwork to accommodate the next pour, we were able to change its detailing to save concrete while still preserving the wood.

We were using prebagged concrete mix to avoid the need to proportion bulk ingredients accurately. I was willing to

pay the premium for this as the mix came in bags of 60 pounds rather than the 94 pounds typical of Portland cement. In our first attempt to reduce concrete in the stem-wall, we stuffed empty mix bags into the cavity of the lower part of the formwork. We covered this with cardboard thus creating a stem-wall with vertical sides. Our next and final adjustment was to cease the building of forms that stepped out at the bottom. In the last phase of stem-wall construction, we installed two or three 2-by-6s in the same vertical plane dividing the gaps evenly between them. We covered these with cardboard which easily held the hand-placed concrete while bulging a little to yield a slightly lumpy surface. The pleasant appearance of the surface (which looked remarkably like stone) was not of consequence, however, as it was below grade. This forming system proved to be very fast, inexpensive, and entirely adequate.

THE FRAMING

Industry literature was adequate for me to size the structure and detail the framing. The house is framed with 6-inch steel studs which set 2 inches inside an 8-inch concrete block exterior wall. The resulting 16-inch thick walls give the house a sense of mass desired for aesthetic reasons. Although



Fig. 2. Ziggurat formwork in foreground changes to the final version in the background.

we were willing to pay more than the cost of basic construction to achieve our aesthetic goals, it was not necessary in the case of the exterior walls. The concrete block wall is thick enough to take the wind loads thus leaving only the gravity loads to be carried by the steel. The reduction of loading on the studs allowed the use of thinner steel compared to traditional detailing. The \$8,000 saved by using 20-gauge instead of 18-gauge studs and by using 3-5/8-inch instead of 6-inch studs in the gables paid for the excessive thickness of the block weathering surface. Other combinations of materials for the walls were rejected as being more difficult for us to assemble and insulate.

The 8-inch wide blocks had an important advantage over thinner units since we had never laid any type of masonry before. The 8-inch wide blocks are easier to set nearly level by eye and easier to adjust with a spirit-level than are 4-inch wide units. The prospect of laying 15,000 blocks without knowing how intimidated me into several complicated plans to compensate for my lack of skill. Such schemes as dry-stacking or using spacers in the mortar joints were eventually discarded. We laid two magazine articles about concrete block on the ground and began learning to lay block by reading the instructions. I laid twelve blocks the first day. It took 100 blocks to learn the basics of the procedure and my speed increased until, after laying over 2,000 units, I peaked at 95 standard weight 36-lb blocks a day. Laying block turned out to be much easier than I had anticipated.

One-hundred blocks a day is a reasonable rate for an amateur with about 200 being the norm for a professional. I expect my pace to increase when I lay the light-weight 27-lb units in the super structure. The laying of the 45-lb U-blocks slowed the work as in addition to their weight, their configuration made handling difficult. Also they were misshapen due to sloppy manufacturing. Their slightly curved surfaces made consistent leveling impossible. Perhaps the worst aspect of the U-blocks was the need to drill holes in them to receive vertical reinforcing. The block supplier tried to convince me to use lighter units with knock-out webs in lieu of the U-blocks. My refusal to listen to him

was a mistake symptomatic of inexperience combined with a mistrust of sales motivations. The work was near perfect in the lowest block (now underground) and dropped in quality as I moved faster seeking the limit of irregularity that was acceptable in the exposed walls.

THE DESIGN

We could not use any component heavier than my wife and I could lift which eliminated using hot-rolled steel to carry block walls over open space. Concrete beams longer than typical lintels were beyond our expertise also. Consequently in the initial design all the concrete block walls rested directly on the foundation. This forced a simplicity into the design as it eliminated the possibility of changes in the vertical planes of the exterior walls. Any large-scale texture desired in the facade had to be achieved by variations in the perimeter of the plan. The result was twelve exterior corners and eight interior corners on the exterior of the building.

The conservative approach to the design adversely affected the scale of the building. My goal of having a simple gable roof with no valleys or interruptions to the drainage of water combined with the block-wall restrictions resulted in an excessively large attic space. That is, because the house is wide, the roof planes rising from opposite eaves at an 8/12 slope form a ridge 15 feet above the attic floor. Without giving up certain design goals, I could not reduce this attic volume without passing a block wall over open space below. After laying 2,500 foundation blocks and installing half our steel framing I gained enough faith in the integrity of reinforced block and the stiffness of 16-gauge joists to realize that the steel could be detailed to carry block. At any time before this point I could have come to this conclusion though calculations but I needed an intuitive sense of the material to verify what the numbers indicated.

Now we could lower 12-foot lengths of roof on the narrow masses at each end of the house to a 7-foot high ridge in the attic. Only 8-foot sections of the attic facing the courtyard would be left with the high ridges to facilitate drainage across

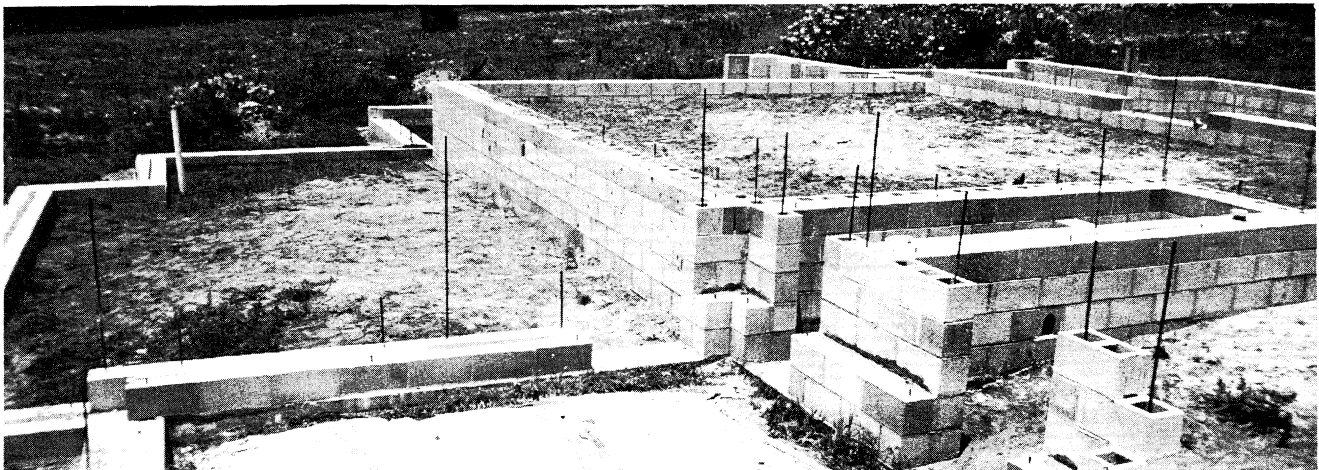


Fig. 3. The block portion of the foundation from the east.

the widest part of the house. The sense of waste was eliminated and the scale of the house moved closer to my goals. At this point, the house was no longer being built by two inexperienced and unskilled people. After inspecting similar work in the community it is apparent that we are now able to lay concrete block and assemble light-gauge steel to closer tolerances than much of the work in our area. In addition to our framing expertise, we have acquired a limited scope of plumbing skills, our first floor water and drainage systems having been praised by the city inspectors. Our newly acquired technical competence does not make us professionals, however, because our large safety factors and small tolerances impede our pace while increasing the amount of materials required to a point that would be unprofitable if the labor was not free.

Much of our 20-gauge steel is slightly curved and some is dented. The components we ordered pre-cut to specified sizes came with lengths varying as much as 7/8-inch from the longest to the shortest. As one must do for wood, we have sorted, cut, and straightened pieces so as to minimize their affect on the work. Due to a worn or misadjusted rolling mill, the flanges of the 16-gauge joists are flared excessively. In our installation of the irregular joists we have attempted to compensate for their extra depth but have been unable to do so in every case resulting in elevation inaccuracies. Due to

their strength we have been unable to straighten all the joists that were curved thus some are in place with a slightly impaired spanning capability. When the manufacturer was able to deliver only half our initial \$20,000 order (which did not include the pieces necessary to begin the work), we canceled the remainder and reordered elsewhere causing further delays.

We had expected that the steel assembly would be easier than that of wood but it is not. Driving screws into the steel takes a surprising amount of force and precision. It is particularly difficult when working in an awkward position, a common circumstance for the 60,000 screws required in this house. Selecting the appropriate screws for the work was one of the more difficult planning tasks. Based on common practice in our area and an article in a building magazine we selected a palate of phillips-head screws which turned out to be difficult to use. After struggling to insert several hundred of these we happened to purchase a mislabeled box and found inside hex-head screws which became our standard fastener.

CONCLUSION

Our limited work-force and simple equipment have generated several minor innovations as we must solve our problems with logic rather than the experience which would have

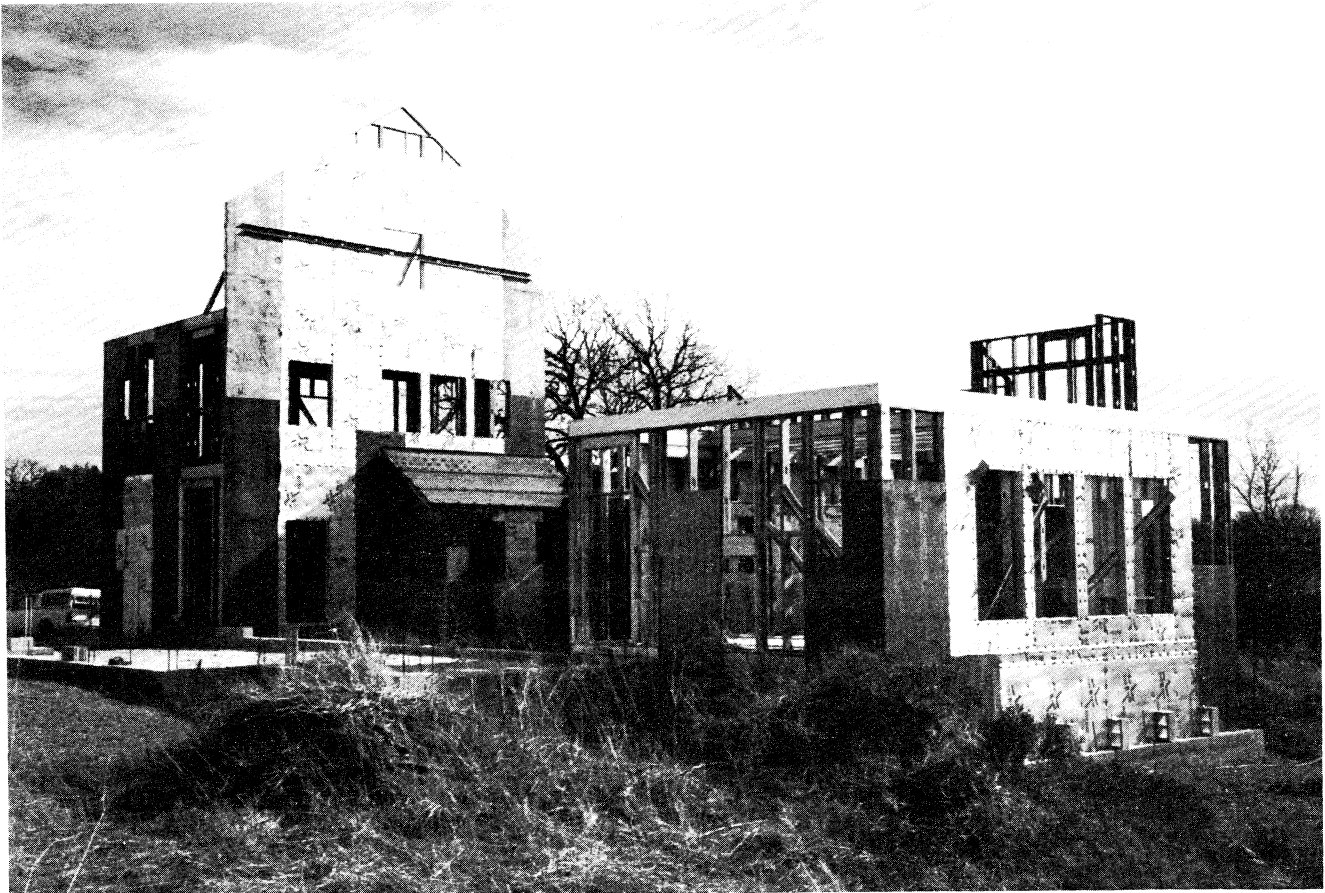


Fig. 4. The construction from the northwest.

tended to produce more conventional results. The composite wall is a new idea and enhanced aesthetic value at no extra cost. The cardboard system for the foundation framing preserved lumber for reuse while being economical and fast. The scaffolding system will incur no overhead cost as it will be fabricated from the foundation formwork and light-gauge steel that will later become the undercarriage of the decks. Our garage floor will be a unique assembly of patio block as we cannot do concrete flat-work. We will install the plywood roof sheathing in 2-foot-by-8-foot panels thus gaining the handling advantages inherent in boards while avoiding problems with the wind. To assure flawless surfaces on the 79 concrete lintels we will precast their faces as one-inch thick panels. Those panels which are too heavy to lift (such as for the garage doors) will be cast on scaffolding and tilted into place. The precast faces will act as permanent formwork for the structural concrete cast-in-place behind them.

Since beginning this project I have been called by three people requesting consulting for their self-built buildings. Their projects, two houses and a horse barn, are all in light-gauge steel as the referrals came from my steel distributor. The potential clients had the enthusiasm, labor, and financing to proceed with the work but did not have the theoretical background needed to learn the steel framing process on their own. The inquiries suggest the presence of a limited

consulting market appropriate for university faculty. Advice regarding tools, fasteners, and processes would have been valuable to us, for example, at the beginning of our project. Also it would be helpful to any amateur-builder if materials could be purchased through a consultant so as to gain the advantages of leverage and price-breaks that would come with the consultant's history of bulk purchases. A consultant could also identify trustworthy subcontractors and might supply some equipment.

According to Francis Bacon, "Truth emerges more readily from error than from confusion." At times our friends in academia and the building industry are horrified or amused at our efforts but no one has accused us of lacking direction. My office-bound experience and academic background proved adequate for planning and implementing this project which has yielded thus far a sound construction within the limits of our budget. The errors we have made (numbering beyond those described here) have been frustrating but not debilitating. Lessons learned have been integrated into my teaching of building materials and mechanical systems while the project has served as a study vehicle for students in other instructors' classes. As an academic who does not practice architecture, the project has provided me with a mid-career reality check and has opened the door to further exploration of "low-tech" building through consulting in the self-help projects of others.