Experimental Student Family Housing: Lessons from Design and Construction

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INTRODUCTION AND OBJECTIVES

The University of Oregon is located in a bioregion historically dependent on timber production as an economic base. This experimental housing project is part of a regional effort to stimulate new businesses capable of adding value to a declining timber resource while creating new family wage jobs in manufacturing. One of our specific roles in this effort has been the design and construction of six units of family housing intended to showcase the capabilities of new industrialized housing producers in our region. The project also serves a national agenda relative to the development of energy efficient housing types that are designed to be built with new materials and industrial technologies.

The initial project goals were as follows:

- Test the role of industrialized building systems in the production of quality, affordable housing.
- Explore the relationship between these industrial production methods and emerging standards of energy efficiency for the completed units.
- Test the capability of regional manufacturers to generate cost effective building components and systems.
- Promote successful prototypes through documentation of the design determinants and construction processes, analysis of labor and material costs and measurement of the energy performance.

Construction of the model units was financed through state bonding authority granted to the university for development of a larger number of student family dwellings elsewhere in town. The six experimental units were assigned to a residential area adjacent to the campus in which university owned dwellings occupy 60-80% of the lots. Given the user group and site constraints, the project was expanded to include additional issues:

- Test local planning instruments as the means to increase residential density within a neighborhood of older, single-family residences.
- Demonstrate simple concepts of site design: private outdoor spaces, common play areas and solar access.
- Explore unit configurations which are efficient, livable and adaptable to special needs.

The program statement called for five 2 bedroom units, each approximately 750 square feet, with a sixth to include an extra bedroom and bath. This became an opportunity to explore expansion of a small unit within the constraints imposed by the industrialized building techniques.

METHODOLOGIES

The prototype design process was organized as a matrix. The horizontal axis ordered the plan types by level of industrialization, increasing from simple components (trusses) to open panels, closed panels, core units and full modules. The vertical axis began with single, double and triple unit buildings, representing increasing unit densities. As site design alternatives were explored, it became clear that double units would generate the best fit. Similar units in pairs also offered greater control of the energy use monitoring program planned for later phases of the project. Therefore, the matrix was expanded to examine 1 story, 1-1/2 story and 2 story prototypes within the double unit category. Schematic unit prototypes were developed for each cell of this matrix with a bias toward the higher levels of industrialization to differentiate the proposals from conventional practice. Once developed, the prototypes were sent out for review by relevant manufacturers. Through this dialogue we began to gain a sense of what was technically possible and cost effective. With support from an allied research team, we performed a schematic energy analysis of each prototype. As a consequence of these evaluations we selected a range of solutions which combine site-built thermal mass with off-site manufactured elements. Light weight panel and modular units are already widely available, and the addition of thermal mass is an effective energy strategy in our bioregion. Large areas of south glazing combined with insulated floor slabs generate some solar savings in western Oregon's relatively mild winters. Interior daylighting is significantly improved over that which energy optimization would permit without the added mass. On summer evenings, prevailing north winds cross-ventilate the units, cooling the mass for the following hot afternoon.

We began the long process of site design approval concurrently with the prototype studies. After careful examination of the local planning ordinances we elected to develop the units as single family townhouses within a cluster subdivision. This proved to be the only means of increasing the density without a politically volatile zone change. Lot lines internal to the cluster require no setbacks, allowing the unit pairs to be attached. Solar access for both the new and existing units suggested placement of the 2 story, 1-1/2 and 1 story units in a cascade descending toward the north, so that the longest shadows fell within our own building group.

In order to boost density on the demonstration site (eight units, with two existing, on three lots), we imbedded it in a larger cluster of 15 units which meets the area requirement of the present zoning. As a by-product we were able to create lots for older houses relocated from other university construction sites. These fill in the missing "teeth" in the residential block.

Working continuously with industry, we developed generic prototypes (appropriate to our site) for the unit pairs that could be built with either panelized or modular methods. Following two rounds of professional cost estimating, bid documents were prepared reflecting what appeared to be the most effective techniques:

- 1 story: closed panels with structural insulated panels for both the walls and roof.
- 1-1/2 story: open panels combined with attic trusses for the upper floor.
- 2 story: modular second floor over a thermally massive first floor.

DATA COLLECTION AND ANALYSIS

A local contracting firm was selected to supervise the bidding and building process within a construction management/general contractor format. Public bids were collected on all the building components and subsystems with alternates organized in a fashion which permitted direct competition between different manufacturing techniques. After a thorough review of the bid data we put together a revised production strategy.

FINALIZED 1-1/2 STORY PROTOTYPE

The production system for this building could have come from almost anywhere in our matrix of possibilities. In fact, the initial designs used two long modular halves to generate the ground floor with a substantially complete center meeting wall. The upper volume of these would have been generated with deep, I-joist roof cassettes allowing for adequate insulation. A second alternative called for the kitchens and bathrooms of both units to fit within a single factory finished core unit at the center with living space extruded to the east and west by means of panels.

However, as we proceeded through energy and cost analyses, there emerged three formative issues: an insulated floor slab would provide a significant benefit in both heating and cooling seasons; elongation east to west improved solar gain in the main rooms but reduced the north-south width below the economical standard for two long modules; and finally, the attic trusses appeared to be such a bargain that we had to use them. Attic trusses integrate floor joists, knee walls, and thick roof cavities for insulation. With extra space in the roof this appeared to be the best opportunity to demonstrate design for expansion and fulfill our commitment to make one three bedroom unit. The final plan works with the discipline of the attic trusses, using the interruption of the stair dormer to create a more flexible "opportunity zone" where an additional bedroom could be added. An independent expansion of the ground floor in the same zone provides a larger kitchen, dining and living areas for the greater number of occupants.

The 1-1/2 story unit pair was awarded as anticipated to a local firm specializing in open panels for both exterior and interior walls. The firm make extensive use of CAD and has a relatively low-tech production facility which easily accommodated the custom, paneled dormer roofs that fit into the steep, trussed gables of the structure. These roof features were important not only to the nature of a 1-1/2 story design but also as a contextual response to the site's neighborhood of older, craftsman style bungalow houses.

FINALIZED 2 STORY PROTOTYPE

The 2 story prototype is basically a row house with very little glazing on the ends. The plan is elongated from characteristic deep slots to a double square footprint permitting all the main rooms to face south. The bid documents for these units specified a modular second floor over concrete masonry walls. Modular producers in our state are required to use fully licensed plumbers and electricians in the plant, and thus their real competitive advantage comes in framing and finishing. The upper floor therefore contains most of the framed partitions, gypsum board, doors, trim and the bathroom. The lower floor was designed to be essentially open with the masonry left exposed. Kitchen cabinets and stair units are easily prefabricated and the only essential partition acts as the plumbing connection from the module to the ground. This configuration offered a clear separation between the factory finished and site built portions. Our analysis showed that in a relatively mild climate we could not justify the cost of the exterior rigid outsulation and masonry outer walls. The mass floor and central wall were more cost effective. Once the lower floor walls were then switched to wood construction, the panel producers gained an edge in competing for the whole structure. More importantly, we already had plumbers, electricians, and sheetrockers coming to the site for work on the other buildings. Within the bidding structure, these subcontractors' add alternates to finish out the 2 story units were very attractive. Further, the modular suppliers were not attracted to the relatively limited produc-

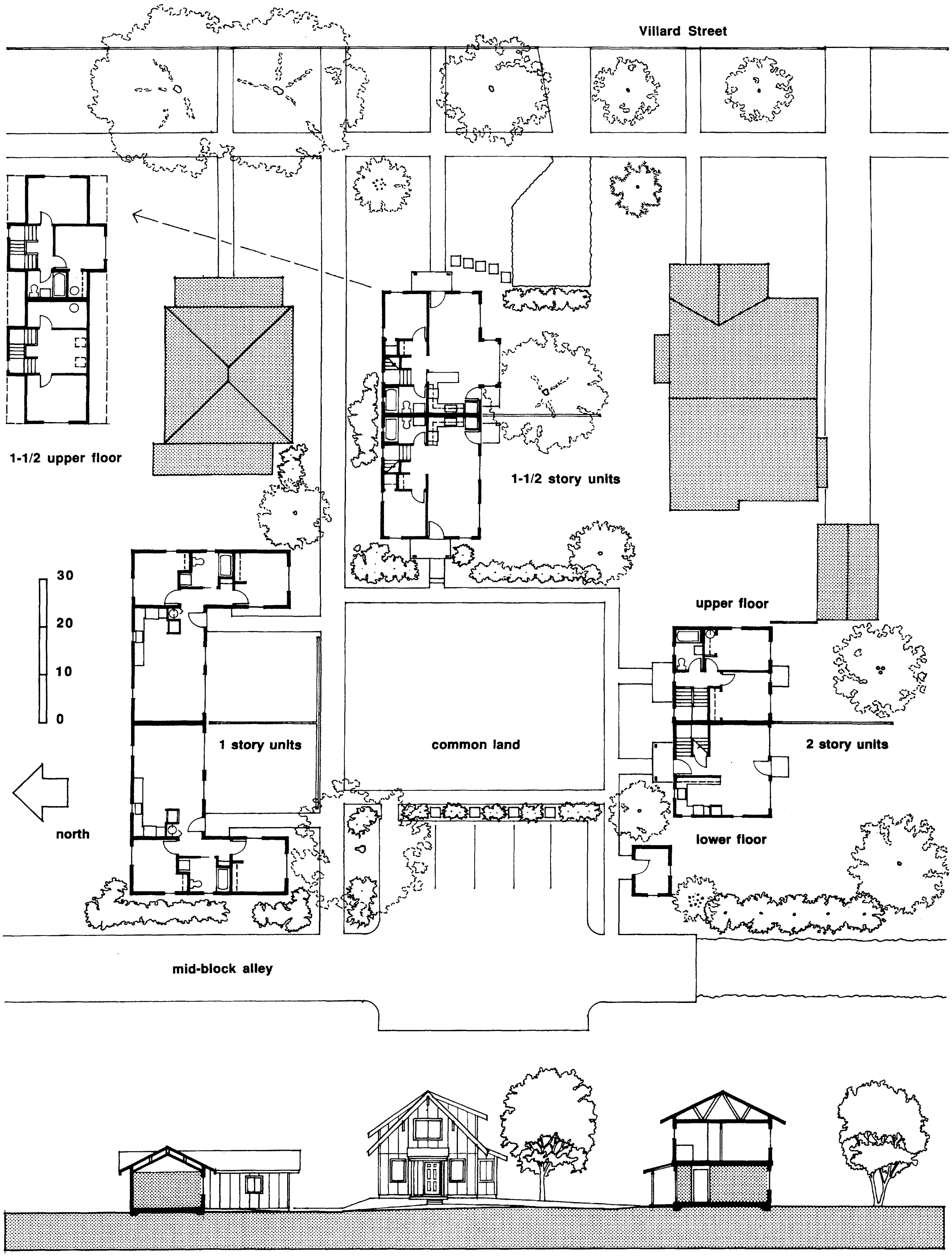

Fig.1. Site Plan and Section. The 1-1/2 story prototype infills a vacant lot between two existing dwellings, while the other two prototypes infill the deep backyards behind these dwellings.

Fig. 2. 1-1/2 story prototype as built: Open panels with exterior finishes and windows installed at factory; panelized interior partitions; attic trusses; double girder trusses supporting panelized dormers and central floor cassette.

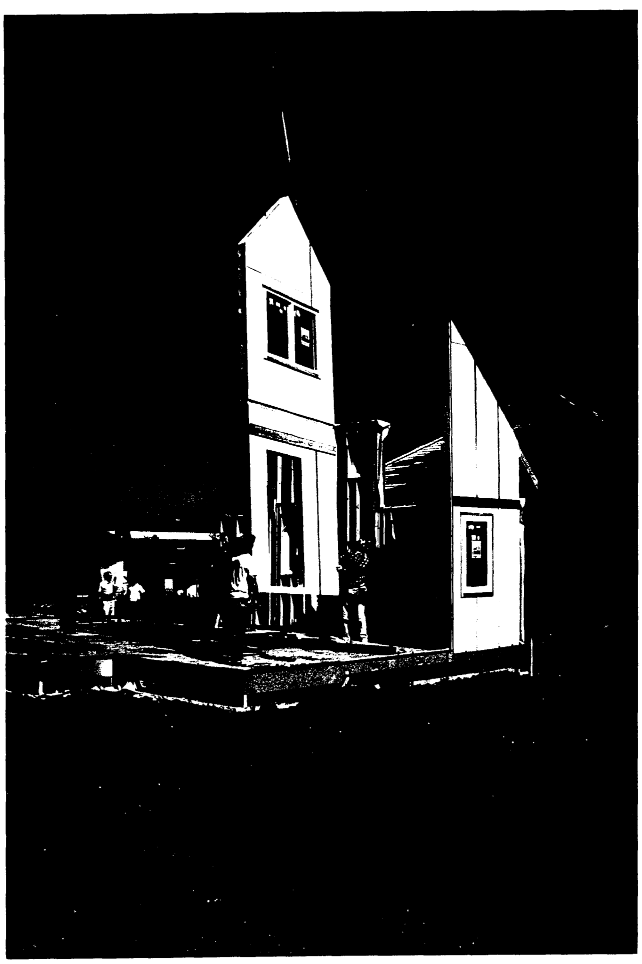

Fig. 3. 1-1/2 story prototype's open panels being craned into place. The exposed framing is visible in back walls.

tion volumes of this project, generally stating that they needed to provide between six and ten identical units before they became cost competitive.

The lowest cost package included wood stud closed panels by a new local firm which had just opened a highly automated, Swedish style, factory crafted panel line. The floor cassettes were also prefabricated in their plant. We worked out the framing plan such that the LVL rim joists act as headers over windows and as a longitudinal beam, reducing the span of the perpendicular cassettes. The panel producer was not prepared to provide stairs and partitions, although it became clear from the 1-1/2 story experience that further savings could have resulted. Closed panels receive insulation, plastic conduit, and gypsum board in the factory. Electrical distribution is resolved in the open floor cassette. The real challenge is in the connections between closed panels. We developed a detail which allows the walls to slightly overhang the base slab with connector plates and tie-

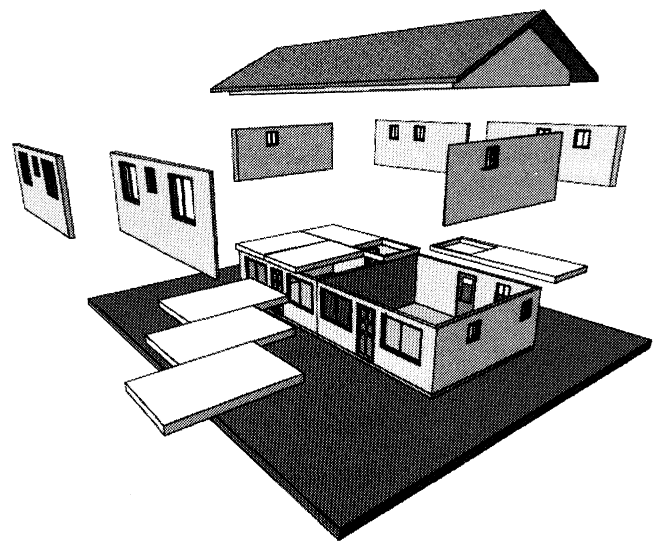

Fig. 4. 2 story prototype as built: Closed wood stud panels with insulation, gypsum board and windows installed at factory; floor cassettes with integral beams and headers; cmu party wall; concrete slab; conventional truss roof.

Fig. 5. 2 story prototype's closed panels being craned into place. The covering protecting the pre-installed gypsum board is visible at back walls.

downs anchored to the slab edge and concealed behind the slab's perimeter insulation. A similar detail was repeated at the second level where the walls were anchored to the floor cassette. This gave us the opportunity for a more expressive detail at the panel junction.

DESIGN AND PRODUCTION OF THE 1 STORY PROTOTYPE

Design of the 1 story units was dominated by site concerns. The units have necessarily large footprints on small lots, and the "L" shape was adopted to preserve useful outdoor space in front of each dwelling. A compact footprint would have enhanced energy performance, but left wider strips of unusable land around its perimeter. The units lend themselves easily to modular construction. At one point we entertained the notion of bath and bedroom modules with the crossing bar serving as an attached, thermally massive sunspace for living and dining. Our energy analysis informed us that to overcome the liability of the long perimeter we needed a massive floor slab under the entire unit with a solar contribution from the south facing bedrooms. Modular producers in our region were interested but have no experience with floorless boxes.

As relatively simple structures, we determined that these units would be a safe test of closed panel construction. Bid documents for walls and roofs were prepared to catch the interest of stressed skin insulating (foam) core panel producers, many of whom have representatives in our region. We attempted to take advantage of large production dimensions to reduce site assembly.

The foam core panel bids we received were quite high, particularly compared to parallel chord roof truss systems with batt insulation. The truss roof further offers a place to resolve electrical distribution to vertical chases in the panels. We also found that any wood stud wall system had a lower first cost by approximately $2.00 per square foot of finished floor area. For the sake of experimentation we elected to build one unit with foam wall panels, at a premium, and build the other with closed wood stud wall panels similar to those of the 2 story. The use of identical truss roofs over both sides gave us a direct comparison of the two wall types. The closed panels went together easily with windows and trim already in place. The low bid foam panel producer shipped small units which required a lot of field assembly and finishing. Electrical runs were a particular problem.

The wood stud panels were designed with both cavity insulation and also rigid insulation between framing and sheathing, providing a higher theoretical R value than the foam core. However, research by others indicates that with reduced thermal bridging and with greater longevity, the foam insulation may outperform theoretical values, a difference we should be able to measure in our long term monitoring program. In our mild climate, the savings may never overcome the initial cost premium. However, in other markets the price relationship between foam and studs is actually reversed.

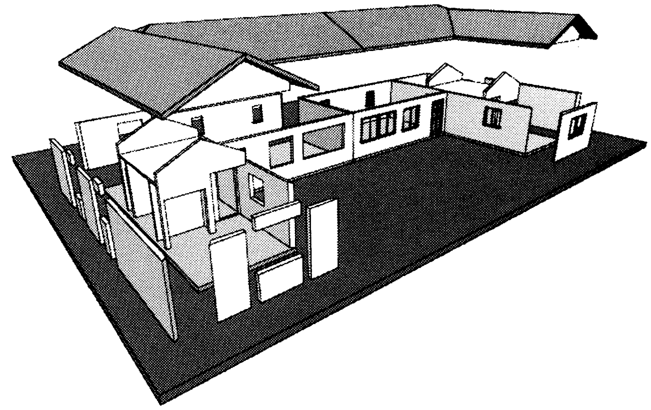

Fig. 6. 1 story prototype as built: West unit: foam core panels. East Unit: closed wood stud panels with windows and finishes installed at factory. Overall: parallel chord truss roof; site built interior partitions; cmu party wall; concrete slab.

Construction of the project proceeded following the acceptance of a guaranteed maximum price (GMP) by the university. Throughout the process detailed time and materials records were kept by the CM/GC. We maintained a daily log of problems and future opportunities as they were uncovered in the field. Extensive photo and video records were taken at each step in the sequence. We are at present working with the CM/GC to complete a retrospective cost analysis to accurately assign the cost of field changes to those sub-systems which caused the problems. For example, the final cost of closed panel systems must accurately reflect problems encountered by the plumber and electrician. However, such changes will be relatively small, and it is already possible to draw conclusions from the recorded costs of the work.

A second phase of this research project began as soon as construction was completed. A series of energy performance tests have been conducted including blower door tests, infrared camera scans, tracer gas tests and simulated occupancy. The units include low voltage sensors and electrical submeters which permit long term monitoring of the ambient climate variables, internal and external surface temperatures and energy use of space heat, hot water and electrical devices. Occupied by student families, the units will be monitored for a period of two years. At the conclusion we will be able to finally compare the actual energy performance with computer modeling completed during the design process.

MAJOR FINDINGS

Residential density on the demonstration site has been increased while maintaining pleasant, sunny private spaces both inside and outside of each dwelling. The average land area assigned to each unit, inclusive of parking and common space, has been reduced to 70% of that required by the present R1 zoning and only 37% of the pre-existing pattern. Critical to this success was a new city ordinance which permits a minimum of one parking stall per unit for student housing. Our qualitative design criteria and setbacks for solar access did not permit us to reach our initial goal of R2 lots at 50% of the R1 area. Nevertheless, the central play area and shared laundry facility should support a strong sense of community which was a requirement of our client.

Spaces within the units are small but efficient. Elongation of the unit plans east to west for solar gain results in longer indoor views across the main living spaces, and the additional glazing area permitted by the use of thermal mass provides generous and welcome daylight in most rooms. The one story units easily accepted the constraints of barrier free design, although the larger corridor widths do reduce spatial efficiency. Visitors to the project have informally expressed an overwhelming preference for the 1-1/2 story units with their traditional appearance. The two story units are strikingly tall with extra roof thickness for insulation, although in terms of land area and construction material, these are clearly the most efficient.

Industrialized building techniques did make a meaningful contribution to the quality and affordability of the finished units. The most experienced producer completed the 1-1/2 story frame and enclosure for $2500 less than the baseline, site-built bids. The 1-1/2 story shell was completed in only three days, while the 2 story exterior reached the second floor top plate in only one day. Given the public financing of this project, no direct savings resulted from the reduced project schedule. However, such savings would accrue in private developments. The most significant issue in public work is the wage differential between the site and factory under the Davis-Bacon Act, contributing more to the factory advantage than frequently overstated productivity gains. Overall, the construction costs were within our budget of $55 per square foot.

The energy performance goals of this project appear to have been met, although more will be known at the end of the two year monitoring. A range of manufacturing techniques were used, and all of the units meet the highest levels of the

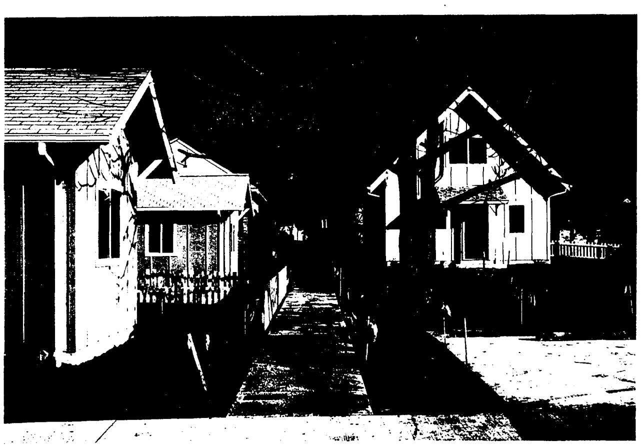

Fig. 7. View from alley showing the two bedroom wings of the 1 story prototype in foreground and midground, and the 1-1/2 story prototype in background.

"Super Good Cents" energy efficiency incentive program sponsored by our regional power authority. This places them well above the most strict current energy codes. Completed tests reveal the units to be tight and well insulated, and the thermal mass was integrated without significant detailing problems or cost penalties. The specific contributions of industrialization are subtle: windows installed in the factory fit well; insulation is more accurate, and the layer of rigid foam board under the sheathing (as well as the building wrap/infiltration barrier) costs much less to install in the factory. Manufactured components like foam panels without studs and raised heel trusses make significant contributions, although these are also available to site builders.

New manufacturers in our area learned a great deal from their participation in the project. The contrasts in their techniques became clear as we progressed. The open panel producers use a very low tech approach in the factory with ingenuity, construction experience and efficient computer usage replacing high capital investments in equipment. As a result, they have great range in what they can panelize and demonstrated savings on dormers, interior partitions and stair cases, in addition to the basic shell. Keeping overheads low and leaving plumbing, wiring and gypsum board to site installation positions them to compete aggressively in our region where on-site costs are still somewhat reasonable. The closed panel builder has a deep investment in equipment and depends on a high volume of highly finished components. The equipment limits design flexibility, and time taken to complete special elements off the line does not help to amortize loans on the plant. With our unit prototypes they were able to reach cost levels which give them easy access to markets in which site based finish work is much more expensive and energy efficient design is of similar priority.

The head to head comparisons of the 1 story units were of particular interest. The closed panel half went together very quickly and at a much lower material cost. Siding, gypsum board, windows and trim went on the foam core panels in the field, and the electrician reported a threefold increase in his labor required to complete the rough wiring. The experience of our energy analysis group indicates that long term savings will accrue from stable insulation without thermal bridges, but it will be difficult to offset the negatives. Nevertheless, the general contractor's forces based on the site had a strong preference for working with the foam core panels, because they felt more involved in traditional hand assembly.

SIGNIFICANCE AND APPLICATION OF THE RESULTS

The limiting factors in making truly affordable infill units have been development costs related to the land and not the unit production. The planning ordinances in our town, Eugene, are still written around the conversion of raw land to low density subdivisions. New instruments are needed to encourage small scale infill within existing neighborhoods. At present the entire regulatory system presumes the existence of large, profitable developers who can and must be compelled to install appropriate public facilities. Single houses on single lots escape the scrutiny and bureaucracy to which this project was necessarily subjected. A small, multiple unit project like this one carries a disproportionate burden of direct costs and added staff time required to coax it through a long approval process. The cluster subdivision opened the door for a seemingly endless list of requirements for the infrastructure at costs which far outweighed the savings realized through industrialized building.

The lessons we have learned from this experiment have already been presented at a national conference on urban design, the NAHB Building Systems Council and to individual manufacturers around the country. Further papers have been accepted detailing the energy performance and monitoring aspects. Our research team works cooperatively with state economic development personnel and the housing division on topics of mutual interest. We have made the case to the governor's office that truly affordable housing awaits a hard look at the priority given to land development costs at the expense of the building stock. This is, of course, a national issue.

The principal investigator on this project has a new grant of support from the state to provide continuing consulting to emerging industrialized builders and component manufacturers. There remains a great deal to be done, particularly in the area of testing and approval of closed panel systems for ready acceptance throughout our state and in others. Manufacturers also need assistance with the development of prototypes for more demanding climate zones and for multifamily densities.

Nevertheless, the ultimate goal of the project, to develop and promote local industry, has been a resounding success. Critical construction details were developed through the cooperative efforts of the research team and the producers. The manufacturing experience and cost confidence acquired along with visual documentation of the assembly process and site tours of the completed units have thus far resulted in a major contract for export of 200 units per month to Japan — no longer raw logs, but closed wall panels and floor cassettes comprised entirely of American materials and labor.