Research, Design and Construction Technologies in Affordable Housing

J. Stephen Weeks
College of Architecture
University of Minnesota
89 Church St SE
Minneapolis, MN 55455
weeks001@umn.edu

John Carmody
Center director
University of Minnesota
89 Church St SE
Minneapolis, MN 55455
carmo001@umn.edu

Mary Guzowski,
College of Architecture
University of Minnesota
89 Church St SE
Minneapolis, MN 55455
guzow001@umn.edu

William Weber
College of Architecture
University of Minnesota
89 Church St SE
Minneapolis, MN 55455
Weber064@umn.edu

ABSTRACT

This paper documents the process and outcomes of a two-year effort at the University to research, design, and build innovative affordable housing. Issues explored in the paper include developing design through research, testing the design through actual construction, applying lessons learned to future projects, and disseminating knowledge into practice. The broad objective of this research is the design and construction of affordable, healthy, socially and culturally appropriate, energy efficient, attractive and sustainable housing. The interdisciplinary team included architects, architecture faculty, contractors and researchers with expertise in design, social and cultural factors, and sustainable building technology. The project is done in collaboration with a local non-profit organization and community development corporation. Phase one of the project was the design and construction of a 996 square-foot (92.5 square-meters) affordable house utilizing innovative construction and enveloping systems. The engineered wood structural system being tested combines un-insulated 11/8-inch (3.8 cm) OSB structural engineered wall panels (oriented strand board) with I-joist floor and roof framing diaphragms. This structural system was combined with the PERSIST (Pressure Equalized Rain Screen Insulated Structure Technique) system of self-healing waterproof membranes adhered to the panel and sheathed by 3" rigid insulating sheets to create a weather tight thermal envelope. One intent of these systems is to reduce material and construction costs by minimizing and eliminating construction steps, such as applying rigid insulation board with embedded furring strips or the direct application of finishes to the panel. Additional intentions are to improve energy efficiency and indoor air quality by increased air tightness and inhibiting mold growth due to moisture infiltration, which has become common in tightly sealed conventional residential construction in the United States. A target cost of $85,000 (US) or less for construction was established.

Phase Two of the project focuses on further development, testing, and evaluation of the design, technologies, and production of two successive Case Study Houses, each bringing forward lessons from the previous case studies. House Two has been completed and House Three will break ground for construction in December 2004. Continuing research efforts include on-site evaluation of construction management, documentation by video and photography and comparison between baseline conventional construction and the PERSIST system applied to the structural engineered panel. This paper will discuss the research project's documentation and critiques and the relative successes of applying lessons learned that modified each successive house in the following areas; energy performance, construction performance and staging, contractor training, interactive education and community input.

1.0 PROJECT GOALS AND OBJECTIVES

The subject of this paper is the design and research of several small affordable, sustainable, and healthy single family houses (House One, Two and Three), constructed in the Frogtown neighborhood of St. Paul, Minnesota, U.S.A on 40 ft by 120 ft lots. This paper discusses the research challenge - providing affordable, attractive, socially acceptable, culturally appropriate, energy efficient, healthy, and sustainable housing - of designing and constructing several single family home using an experimental construction method. The single family home was selected as a building type, because neighborhood infill sites are common to the area and would benefit from alternative low cost solutions. The design would incorporate the social and cultural requirements of predominately Vietnamese and Hmong immigrants, ecological implications of material and design decisions, foundation and moisture mitigation strategies with emerging construction and enveloping technologies.

Beginning in 2001, the Amherst H. Wilder Foundation (a nonprofit social welfare institution with a broad array of work-force housing programs in St. Paul) teamed with the Greater Frogtown Community Development Corporation (GFCDC), the Department of Architecture and the Metropolitan Design Center at the University of Minnesota's College of Architecture and Landscape Architecture to develop designs and construction drawings for one to three prototype houses that integrate affordability with sustainable design, healthy construction, social and cultural responsiveness, and design excellence. The Wilder Foundation and GFCDC coordinated the construction of the first Pilot House with a certified general contractor. The construction documentation and evaluation of House One, completed in Fall 2003, produced construction and detail revisions for the next two houses, House Two and House Three (see Fig. 1).

2.0 DESIGN-RESEARCH TEAM

The design team for the project consisted of university researchers in design, social and cultural issues, sustainable buildings systems, wood building technology, indoor air quality, and moisture control. The research collaborators sought to design prototypes that would test high performance and healthy features in new constructions while still maintaining affordability. The selected building system, *Structural Engineered Panel (SEP)* is a large panel stud-less wall structure made of 1 1/8" OSB panels. The inspiration for this system came from work done in the 1990s by Rob Leslie, who developed a low-tech, low-cost solution for housing needs in third world countries using a system of 3⁄4-inch OSB as both house envelope and structure. The targeted construction cost for the house was between $85,000-$100,000 and mortgages affordable for people at 40-60% of the Twin Cities Median Income. The developer is the Greater Frogtown Community Development Corporation (GFCDC).

In Fall, 2003, after construction had started on the second house, the research project was awarded a $400,000 Housing and Urban Development grant for Community Outreach Partnership Center. The research team renamed *The Affordable Housing Initiative* continue the design-research collaboration just as House Two was under construction. The team's mission enlarged in scope to include affordable housing curriculum development of architects/designers, outreach programs and expanded community participation to further ensure stability and improve the quality of life in low-income communities.

3.0 DESIGN AND CONSTRUCTION

The Pilot Project coupled the stud-free *Structural Engineered Panel (SEP)* building system with the modified PERSIST system. The *SEP* building system consists of a weather envelope constructed of 1 1/8" x 8' x 24' OSB panel walls, engineered wood I-joists and rafters. The PERSIST (Pressure Equalized Rain Screen Insulated Structure Technique) system, developed in Canada, provides the moisture barrier, vapor retarder and air barrier as well as the insulation for the wall and roof assemblies. The entire OSB wall and roof structure is encased with self-adhesive, self-healing 60-mil membrane, applied directly to the primed OSB, in a flat as possible (no wrinkles or air pockets) shingle fashion with overlaps the between the wall and roof sheathing. It can be applied vertically or horizontally but the vertical application is preferable. Rigid 4' x 8' insulation boards, embedded with treated furring strips at 2'-0" intervals, are then placed over the membrane using adhesive and mechanical fasteners, 2-inches on the walls and 4-inches on the roof. Each surface is then sheathed with siding or roofing. The OSB panels employed serves as the structural component and the interior wall finish (gypsum board is eliminated since the OSB panels may be faced with paper or sanded and painted as the final interior finish of the house). The *SEP* technology and the modified PERSIST or *External Thermal Moisture Management System* (ETMMS) promises a reduction in construction costs, a more energy efficient building envelope, and retarding the mold growth.

Fig 1. House One on the right and House Two on the left

The typical 1 1/8" OSB Huber Corporation panel was originally designed for use as industrial flooring resisting extreme wetting conditions. It is manufactured of Southern Yellow Pine chips (other manufacturers typically use poplar) bonded with an ecologically friendly polyurethane resin that can be sanded to a very smooth surface or imbedded with paper in one surface that; when painted, becomes a suitable interior finish. The panel must be buttressed at 12-foot (3.65 m) intervals to maintain lateral stiffness

By combining the systems (SEP and ETMMS) the design promised a reduction material and construction costs by minimizing steps, optimize space use and flexibility, improve energy efficiency and indoor air quality by increased air tightness and eliminate the inhabitation of mold growth due to moisture infiltration. Each successive prototype (House Two and House Three) incorporated design changes and modified construction protocols in order for the designs to be replicated in the marketplace.

4.0 THE DESIGN

The design of each house sought to negotiate among the social, technical, and construction issues of the project by optimizing the whole design rather than focusing on any one of its specific issues and promote a series of small design ideas rather than achieve a universal solution. The 1 1/8" inch-thick Huber panels required a shift in design conception since the wall became an assembly of sheet goods; the OSB behaves like a continuous beam so joist hangers for floors and a roof can be directly attached to the surface or openings can be cut out with no additional framing. The weather envelope performs best as a simple four-cornered box to minimize cost and permit easy installation of the SEP panels and the PERSIST system. Contextual features such as porches are 'attachments' to the basic box. Open plans and large kitchens provided for flexible family functions as well as assisted in ventilation and thermal performance.

The elimination of the stud cavity found in vernacular construction methods, often a source for mold or deterioration in the tighter insulated walls, also meant the elimination of the traditional distribution network of electricity, plumbing, or heating equipment. Areas for plumbing risers and runs, radon and HVAC distribution are carefully planned near the center of the house. Electrical raceways are incorporated in an extended baseboard trim designed specifically for this task. Vertical trim around doors houses electrical switches. Interior trim is also employ to joints in the interior an important issue since there is no secondary interior finish throughout most of the house.

House One is a 24x24, one-and-a-half story one bedroom 1000 sq feet house, with a single bathroom ('visitable') on the main floor and a full basement that could be remodeled as additional bathroom, bedroom and family room. The main floor was relatively open, given the side entry and stair alignment across the width of the house The second story had one bedroom, a wider open room adjacent to a rough-in bathroom, which served as the master bedroom's walk-in closet. The stick-framed 12:12 pitch roof rests on a girder beam supported on a central column. Details include a slatted stair grill, an OSB pedestal sink, a wrap-around front porch and back stoop, thin-profile alternating siding and wide trim that reflects neighborhood scale.

Fig. 2 Pilot House (House One) Lifting the gable end wall

Fig. 3 Placing OSB panel floor between wall panels

House Two, the 'Narrow Lot House', immediately adjacent to House One (see fig. 1), is a 18 x 32, one-and-a-half story two bedroom 1200 sq. ft. house elevated five feet off grade to provide more security on the corner lot. It has a centrally positioned u-shaped kitchen, eating bar and nook below table height windows. A compartmented bathroom, laundry and mechanical room divide the two generous lower level bedrooms, one facing the facing the rear yard the other the street, all accessed by the straight-run stair behind the kitchen. The living room, entered from the side, across an ell-shaped two-tired porch, is open to the rear yard, and a windowed loft nestles above the kitchen under the cathedral ceiling, overlooking both living and dining spaces, I-joist rafters 24” o.c. span the 18’ between the gable ends. The 1/2 bath on the main floor, accessible from the rear entry, is off the family/dining room (see Fig. 4 for construction sequence).

Fig. 4 house Two: corner panels and one joist ; all panel, windows and rafters in place membrane and windows await insulation

House Three is a 24 x 28 one-and-a-half story three bedroom1280 sq ft, house, again with a full-unfinished basement, but one-and-a-half bathrooms. This plan has a smaller entry front porch, a living room across the street façade separated from a broad family - kitchen area that opens onto a wide deck overlooking the rear yard by a center u-stair opposite a 1/2 bathroom and plumbing-mechanical core backed-up to the kitchen plumbing wall. 85% of the interior bearing walls are 1$^{1/8}$” OSB panels supporting the stairs and the floor I-joists. The floor is also 1$^{1/8}$” OSB panels and the roof is a custom A-frame truss accessible for storage (see Fig. 5).

Fig. 5 House Three first panels w/ 4x4 corners panel shell w/ partial membrane insulation over wall and roof membrane

6.0 CONSTRUCTION SEQUENCE

Major soil conditions and site-availability schedules modified the original shallow foundation design to a poured concrete basement construction for all three Houses; soils remediation, special foundation waterproofing, extensive insulation, egress windows and large window wells were added to make the basement habitable. Because the standard panels were not available for House One, each wall was fabricated from two offset 3⁄4” OSB panels, glued and screwed together, to make 12 foot-high x 1$^{1/2}$” -inch-thick side wall panel's and the entire gable end panels with all window openings. These were lifted off the floor cap in sequence until all four sides were locked together. Floor joists supporting 3/4" OSB panels serve as both underlayment and finished floor, although sanding improves the durability and finish quality of the floor. On House Three, the 1 1/8" x 8' x 24' OSB panel was installed as the finished floor deck requiring the I-joists to be spaced @ 19" o.c. rather than 24" o.c.

House Three exploited the delivery of Huber panels to a local wood fabricator for precutting prior to site delivery. On site, a crane sequentially placed each pre-cut 1 1/8" x 8' panel (bearing height 17') with pre-attached 4x4 corner posts. All panel connections were made as 8" wide OSB battens. House Three's panel fabrication, floor and roof erection, appearing in all respects like a "house of cards" (see Fig. 5), had to be conventionally braced until second floor I-joists were anchored into their plate hangers; erection time was reduced to three days (4 person/day) rather than 12 days on House One (2 person/day).

All Three Houses required care in squaring to properly align the roof ridge, the second floor I-joist and rafter framing. The roof was difficult to sheath, insulate and shingle because of the steep 12/12 pitch and worker safety became an overriding concern. Application of the exterior moisture and vapor membrane was more difficult than anticipated mostly due to uncommon practices.

8.0 CONCLUSION

There is no single design and construction solution to the problem of affordable housing. Incremental improvements have been made in a variety of areas that result in an affordable house that is also more sustainable, healthy, and livable. A few notable results learned from the prior two houses have been incorporated as House Three begins construction.

- The type, size and handling of the 1 1/8" x 8' x 24' OSB panels has improved the quality, strength and efficiency of construction: crane lifts are sequenced, interior panels are sequenced with structural stair elements, to name a few.
- Labor costs have been reduced as contractor and client learning curve has improved.
- Preliminary data suggests moisture intrusion has been controlled better than hypothesized.
- The building envelope has performed higher than expected; the airtight system has produced very high ventilation control measurements..
- Energy efficiency goals will be met but % of improvement is yet to be measured.
- Sub-contractor training and quality assurance has improved beyond expectation.
- The cost of high performance systems is offset by cost reductions in areas such as quantity purchases of building materials (panels) to keep costs on a par with conventional construction.

However, to bring this new building system to scale, there will need to be additional research and development in three areas.

First, the SEP system will require code and regulatory testing to achieve broader acceptance by municipalities as well as the design and construction communities. Testing will primarily focus on identifying problems or opportunities in building codes and standards and other regulations affecting the technology; developing new structural engineering standards and fire regulations; and documentation showing how SEP technology complies with the intent of proposed energy regulations. Each house will be tested and monitored for a variety of performance measures, including energy performance, air tightness and air quality. The Huber OSB panel is undergoing moisture and thermal performance testing.

Second, the mechanical systems integration design must be refined since the ETMMS system supports greater innovation than currently being specified. HVAC, plumbing and electrical systems designs need to be integrated with the manufacturing and panel assembly methods as well as systematized to make them easy to modify, maintain and most importantly function predictably and efficiently.

Finally, building the SEP homes requires education and training of: builders to become familiar with manufactured panel systems; education of architecture students and architects in affordable housing design as well as emerging digital manufacturing document production methods; and building system fabricators organized to work from digital manufacturing tools to pre-fabricate panels and components.

The overarching objective is not the production of a significant number of affordable dwellings but, rather, a set of dependable construction details and specifications that can be used by any contractor wishing to use this construction system. The obvious conclusion to this demonstration culminates in producing affordable, energy efficient, sustainable and healthy homes to the marketplace at a reasonable scale throughout the State of Minnesota.

ACKNOWLEDGMENTS

The Project Design-Research Partners were many: Amherst H. Wilder Foundation, Tom Schirber, Community Housing Liaison (Project Coordinator). The Department of Architecture group, responsible for building design and documents consisted of Mary Gusowski, Associate Professor (Project Coordinator), Lance LaVine, Professor (Architect), Julia W. Robinson, Professor (Social and Cultural) and Stephen Weeks, Associate Professor (Architect and Construction Methods and Materials), the Center for Sustainable Building Research, John Carmody, Director (Sustainable Design), William Weber, Research Fellow (Sustainable Design) and Rebecca Foss, Research Fellow (Sustainable Design) who has been developing a CSI format sustainable specification, the Cold Climate Housing Program, Pat Huelman, Associate Professor (Construction, IAQ, and Mechanical Systems), Marilou Cheple, Instructor (Construction, IAQ, and Mechanical Systems), the Metropolitan Design Center, Ann Forsyth, Director (Sustainable Landscape Planning), Regina Bonsignore, Senior Research Fellow (Sustainable Landscape Planning) and Frank Fitzgerald, Research Fellow (Sustainable Landscape Planning) produced contextual site planning documents that staged varying garden/planting schemes for the Community development Group as well as homeowners. The contractor St. Clair Builders provided construction supervision and cost management resources according to the design documents and committed to training a limited number of staff.

The Center for Sustainable Building research has incorporated the SEP building systems research with its Minnesota Green Affordable Housing Guide The Guide is a web-based resource to assist designers, contractors, and housing agencies integrate affordability and sustainability for cold climate housing. Separate strategies are developed for Homeowners, Developers, Policy and Decision Makers and Designers and Builders, (http://www.csbr.umn.edu/housing_guide.html).