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'Design and Technology for Energy Efficiency in Housing — 2030'

by

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One paragraph abstract

This paper reports on method and results of 'Design for Energy Efficiency', a design and technology task area of the Energy Efficient Industrialized Housing research program — a project jointly based in institutions of architecture, energy research and industrial engineering. The paper presents a research method through which design studies were systematically developed to establish a vision and quantifiable goals for energy efficient housing in the year 2030. Problem definition, design, and performance specification phases of this task are summarized, emphasizing areas where principles of design and technology have converged to realize high standards of economy, energy performance and quality in housing. Goals of 'zero net energy use' and 'zero net cost increase' were established for specification phases of the task.

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This paper presents the methodology and results of one task area within a comprehensive research program in Energy Efficient Industrialized Housing funded by the U.S. Department of Energy. This multidisciplinary research program is a multiple year collaboration of a school of architecture, an energy research center and a school of industrial engineering. The specific task area described integrates research in technology with design. In this task, the design disciplines of the research team have set out expectations of future energy efficient housing through a series of problem statements, design studies, and performance specifications for housing in the year 2030.

Throughout, issues of production, technology and design have been considered together as a means to define designs, design processes, materials, components and manufacturing processes necessary to energy efficiency in the housing stock of the future. The focus of this paper is the process through which a vision of future energy efficient housing was defined, visualized and ultimately quantified. Particular emphasis is placed on areas where principles of design and technology have converged to realize high standards of economy, energy performance and quality in housing.

Background

The Energy Efficient Industrialized Housing research program was established in 1989 to improve the energy efficiency of houses as the construction processes that make them evolve toward increasingly industrialized materials, components and processes. This research program is intended to develop technologies, design strategies, and production processes that will lead to houses that are more energy efficient, of higher quality, and less costly in the future.

While energy efficiency is the research focus, energy is studied in a context of production and design. Studies in the technology of manufacturing strive to deliver energy efficiency, economy and production quality through technically advanced materials and processes. Studies in design strive to ensure that technically advanced materials and processes are well integrated in economical, energy efficient, marketable houses that meet the needs of the people who will live in them.

If the historical record of design and technological change in mature industries such as housing construction holds, the knowledge and ideas initiated today may not be in common practice for two generations. Forty or fifty years may lag between the initial awareness or knowledge of an innovation to its recognition, passage through decision making and learning processes to its ultimate acceptance and adoption in practice. Characteristics of housing demand, design and construction will likely change substantially over that period.

In order to influence this evolving future housing stock, the research program had to anticipate and begin to define a vision of the circumstances, products and processes that will characterize that housing stock. One task area, Design for Energy Efficiency, set out to establish this vision through a series of design based studies for housing in the year 2030. These studies would represent a common ground for a multidisciplinary and dispersed research team, and, define a series of goals to which immediate research activities and objectives could be directed.

Figure 1 outlines the research role of the Design for Energy Efficiency task. Through it, long range speculative design studies enable a multidisciplinary research team to identify and define the specific short and medium term questions that advance a broad and comprehensive goal.

< insert Figure 1 >

Figure 1
Research Role of
Design for Energy Efficiency Task

Several steps were critical to formulating this vision. The overall process is summarized in Figure 2 and elaborated by stage in the narrative following.

< insert Figure 2 >

Figure 2

Overview of Stages in Development
of Design for Energy Efficiency Task

Early in 1990, we set out to define a design context for housing and energy conservation in the future. Literature surveys were undertaken to identify and assess trends across seven areas of influence. Fifty-five trends were identified in computing and design process; manufacturing process; construction materials, components and systems; energy and environment; demographic context; economic context; and planning policy and regulatory context. From these trends, we compiled four housing design scenarios or problem statements, developed eight architectural design studies and evaluated the results.

In 1991, we concentrated on systems (structure, mechanical, manufacturing, etc.) development of two of these designs — a multi-family concrete panel house for hot-arid climates, and a single family composite wood frame and thin insulation house for cool climates. For each, we developed performance specifications that quantify the projected and desired advances in design, construction, and manufacturing systems necessary to achieve energy efficiency with economy and quality.

Trend Highlights by Area

Computing and Design Process

Computer literacy continues to increase throughout the work force. This creates opportunity to customize industrialized housing design through computer aided sales, marketing and design, and to fully coordinate site installation with manufacturing and design processes using computerized design and production tools.

Manufacturers of computer hardware are producing equipment which offers increased computing capacity at less cost. Increased computing capability gives software developers the opportunity to create tools which are able to design, engineer, assess regulatory compliance, energy performance and cost concurrently, and evaluate energy conservation alternatives throughout design and manufacturing processes.

Manufacturing Process

Manufacturers continue to develop products and options and to improve production flexibility. These changes allow for opportunities to define flexible manufacturing and dimensional systems accountable to energy performance standards.

Quality control standards continue to increase which establishes opportunities to improve and confirm compliance with energy performance specifications and assumptions throughout manufacturing.

Manufacturing innovation is evolutionary and provides opportunities to improve energy performance standards as a new manufacturing process is developed and adopted.

Materials, Components and Systems

New technologies using composite and biomass-derived materials are being developed for construction which have the opportunity to enhance energy performance and manufacturing properties of engineered materials.

Increased thermal properties of lightweight materials will provide new opportunities to improve thermal resistance and storage in light, thin wall construction.

As energy systems miniaturize, opportunities increase to manufacture photovoltaics and space conditioning appliances to be integral with construction materials and components.

Greater integration of mechanical and electrical systems provides opportunities for rationalized service core and space planning.

Energy and the Environment

Consumer demand for conservation efficiency increases and pressure is placed on manufacturers and builders to realize energy conservation opportunities across a full range of design and manufacturing processes including, for example, at neighborhood and site planning design scales.

Public demand for air quality continues to increase. This provides an opportunity for community and neighborhood planning strategies to include less automobile use and manufacturing strategies which will use materials and processes of low toxicity.

Worldwide concern for global warming increases and will create an urgency to develop non-fossil residential fuel sources, increase planting levels of oxygen-giving trees and plants, and decrease use of chloroflurocarbon based materials in construction.

Utility load management strategies will seek to defer peak load demand and develop means of electricity generation in houses.

Demographic context

Changes in household composition increases as families and lifestyles undergo transformation. These changes establish demand for flexibility in house size and interior space organization.

As workplaces decentralize, it prompts a demand for mixed use neighborhoods and in-house workplaces.

Population migration and growth concentrates in southern and western regions of the United States. This shift of population establishes demand for new housing in predominately cooling climates.

Population growth concentrates in metropolitan suburbs which establishes need for energy conservation strategies appropriate to multi-family and densely sited single family houses.

<u>Economic context</u>

Land and infrastructure costs continue to rise which establishes need to develop energy conservation and energy distribution strategies appropriate to dense site planning.

Entry level housing markets expand as first time buyers increase demand for low first-cost houses that can be remodeled and upgraded.

Remodel and 'do it yourself' markets expand establishing need to develop energy conserving materials, components and systems for piecemeal, low skilled installation.

International markets and competition increase which establishes need for construction systems based on interchangeable components and international performance specifications.

Construction sector stratifies at national and local scales which establishes opportunity of two tiered construction and energy conservation strategy. Building parts manufactured and distributed at a national or international scale meet national standards,and parts manufactured and installed at a regional or local scale meet local market, climate and utility standards.

Mortgage alternatives increase which establishes opportunity to consider energy conservation as a life cycle cost and finance energy systems separately.

Planning policy and regulatory context

Utilities increase conservation and load management incentives which may include opportunities to economically upgrade space conditioning appliance quality, control devices, construction quality and the thermal properties of materials and components.

Housing affordability incentives increase and prompt a redefinition of planning, zoning and building regulations to mix land uses, reduce development and utility costs, and encourage community scale transportation and energy systems. Land subdivision and ownership alternatives increase which establishes need to develop energy conservation strategies for a range of irregular house and site configurations such as cluster, zero lot line, Z- lots, and zipper lots.

Performance codes replace prescriptive codes which establishes opportunities for code compliance with innovative passive energy conservation design, engineering and manufacturing strategies.

Design Studies for 2030

Many future housing demand scenarios could result from these and other trends acting on the diverse housing markets of the United States. We concentrated further research on four climate zones and housing types developed for elaboration as design studies — Starter House for a Hot-Arid Climate; Move-up House for a Hot-Humid Climate; Extended Family House for a Cool Climate; and Renewable House for a Temperate Climate. These were selected for their broad opportunity for innovation in energy conservation, housing design and manufacturing across a representative range of house types, markets, construction systems and climates.

The 'Starter House for a Hot-Arid Climate (Phoenix, AZ)' problem statement explores energy conservation opportunities compatible with trends anticipating strong demand for small, minimum cost multi-family houses in sun-belt suburbs, diversifying household composition, declining wood resources, advancing concrete technology, increasing site density, and increasing competition for cooling energy.

The 'Extended Family House for a Cool Climate (Minneapolis, MN)' problem statement explores energy conservation opportunities compatible with trends anticipating demand for median cost infill single family housing in northern metropolitan suburbs, improving performance of insulated panels, decreasing availability of dimensional lumber, increasing engineering capabilities of wood composite materials, and increasing computer coordination of design and engineering processes.

The 'Move-up House for a Hot-Humid Climate (Miami, FL)' problem statement explores energy conservation opportunities compatible with trends anticipating demand for above median cost single family houses in Florida, increasing demand for custom design flexibility and quality, increasing competition for peak period energy, miniaturization of variable air volume distribution systems and increasing utility participation in energy conserving construction programs.

The 'Renewable House for a Temperate Climate (Seattle, WA)' problem statement explores energy conservation opportunities compatible with trends anticipating strong future demand for remodels, additions and upgrading of existing houses, increasing sophistication of 'do-it-yourself' building materials and components, increasing computerization of design, engineering and construction management processes, decreasing availability of dimensional lumber, increasing recycling and regulation of toxicity levels in building materials.

Each problem statement developed a set of goals, objectives and criteria that define the market, manufacturing and energy requirements from which a design study could be initiated. These include:

- A scenario of household characteristics and goals
- A delivery scenario of the whole process through which the house is conceived, designed, manufactured, assembled, marketed and financed.
- A design program of occupancy and design requirements. House size, room requirements, neighborhood context, occupancy and household income assumptions are defined.
- An energy conservation program of demand, utility and conservation requirements. Appropriate passive heating and cooling strategies are defined and design rules of thumb provided.
- A materials, components and systems program outlining the basic characteristics of a construction system. Foundation, envelope, structure, floors, roofs, mechanical and electrical systems to be used are defined.

- A manufacturing scenario of factory management and production characteristics.
- A summary of design, energy and economic goals and criteria against which design studies are evaluated. In all cases, designs must improve energy performance by 25% over current State of California Title XXIV standards with no net increase in total project cost.

Eight design studies were commissioned of designers and architects selected for their expertise in housing design, energy conservation and construction processes. Each study developed a schematic design for a house and site to the requirements of the problem statement. Three studies were completed of the starter house, three (and one variation) of the extended family house, one of the move-up house and one of the renewable house.

Design Study Evaluation

All eight design studies were evaluated against goals and criteria established in the problem statements. Computer simulations of energy performance on four typical days in December, March, June and September were performed and compared. Conclusions were drawn and innovative energy improving design and manufacturing principles inventoried for further evaluation and refinement.

Studies (example Figure 3) of the 'Starter House' (Phoenix) problem revealed opportunities for passive heating and cooling innovations suited to the density, compactness and economy required of low cost multi-family houses. Low cost shading, ventilation and thermal mass can be achieved across a range of construction techniques and site planning strategies.

< insert Figure 3 >

Figure 3

Axonometric of Site Plan
Starter House Design Study
Michael Pyatok Architect

Space heating demand can be virtually eliminated and cooling demand deferred to off-peak periods. All studies eliminated heating and cooling loads on a typical December 21 day. Off-peak mechanical cooling was required to meet heat gains that ranged from 11,210 - 43,287 Btu on a March day, 112,478 - 128,005 Btu on a June day and 87,302 - 210,817 on a September day. HVAC, hot water and power systems of higher first cost but greater energy efficiency can be economically shared from common walls and cores.

Manufacturing efficiencies can be achieved through definition of a limited number of component parts that can be combined with variety and flexibility. Sweat equity, renovation and remodel opportunities must be accommodated within design, engineering and manufacturing processes in order to preserve life cycle energy performance of the whole house.

Studies (example Figure 4) of the 'Extended Family House' (Minneapolis) problem revealed opportunities for improvement in the thermal resistance of an envelope appropriate to the design variety and flexibility of light frame construction. Super insulating materials on very light wood frame construction strategies bring significant opportunities to reduce structural material requirements by as much as one half and simplify site assembly by weeks.

< insert Figure 4 >

Figure 4

Axonometric of Site Plan
Extended Family House Design Study
Center for Housing Innovation

The super insulating envelope substantially reduces space heating requirements and virtually eliminates need for cooling. Much of the heating demand can be met through recovery of waste heat. Three studies eliminated or virtually eliminated heating and cooling loads on typical June and September days. Mechanical heating was required to meet heat losses that ranged from 31,493 - 116,531 Btu on a March day, and 63,598 - 187,843 on a December day.

An 'open' manufacturing strategy based on components and materials from competing but complementary sources is vital to the design and site planning variety customary to this market.

Studies (example Figure 5) of the 'Move-Up House' (Miami) problem revealed opportunity to integrate water recycling systems with manufactured foundation systems. The cooling and heat storage capability presented can, in combination with a design that ventilates well, can significantly reduce demand for space cooling and hot water energy. This study eliminated heating and cooling loads on a typical December day and required mechanical cooling to meet heat gains of

37,531 Btu on a March day, 257,818 Btu on a June day and 296,378 Btu on a September day.

< insert Figure 5 >

Figure 5

Perspective
Move-up House Design Study
Winslow Eliot Wedin Architect

Studies (example Figure 6) of the 'Renewable House' (Seattle) problem revealed opportunities to upgrade energy performance in existing residential construction in conjunction with owner built additions and remodels. Among the effective strategies are upgraded insulation levels in walls and windows, improved plan zoning, windows and finishes for passive heating, and upgraded space conditioning appliances.

< insert Figure 6 >

Figure 6

Construction Strategy
Renewable House Design Study
Loveland and Barnes
University of Washington

Energy simulations of the study submitted revealed that the renewed house (upgraded 1,274 square foot existing house plus 700 square foot addition) used less energy than the original house alone. This study eliminated heating and cooling loads on a typical June day and required mechanical cooling to meet a heat gain of 14,382 Btu on a September day, and mechanical heating to meet heat losses of 77,171 Btu on a March day and 123,520 Btu on a December day.

Systems Development

Following evaluation of the eight design studies conducted in four climate zones, the scope of design study areas narrowed to two and increased in depth from schematic designs to systems development. The studies identified for development were selected for their significance to national residential energy consumption and industrialized housing demand in the future. They were:

- A multi-family lightweight concrete panel house for a hot arid climate
- A single family wood composite frame and thin insulation panel house for a cool climate

The former is primarily a heating climate and the latter a cooling climate. Both are regions projected to sustain new housing demand into the next century. Panelized construction systems are fundamental to the design and installation flexibility sought in future markets for industrialized housing. Engineered wood composites and lightweight concrete are projected to be common materials in future industrialized housing.

For each design study, the following summary principles were compiled from evaluated schematic design studies and became base criteria for systems development and refinement.

A Multi-Family Lightweight Concrete Panel House for a Hot Arid Climate

Energy conservation and site design considerations:

- Preserve opportunity to utilize site energy through ground to sky ownership and control of individual units.
- Establish site planning rules to protect access to sun, wind and light.
- Reduce surface area with attached house forms.
- Reduce area of roads, parking and utility systems.
- Increase site shading and humidification.
- Promote utilization of unconditioned outdoor living areas.

Energy conservation and house design considerations:

- Organize houses in two stories of reduced skin and floor area.
- Zone floor plan to keep living areas in contact and control of sun, wind and light.
- Temper micro-climate of outdoor spaces adjacent to living areas.
- Establish loadbearing structure parallel to direction of sun and wind.

Energy conservation and component design considerations:

- Increase thermal storage capability of materials and finishes.
- Optimize the design, engineering and manufacture of roof and floor systems.
- Provide lightweight, adjustable shading and ventilation accessories.

Energy conservation and service system design considerations:

- Combine and integrate energy consuming systems and services in a core wall.

- Supplement passive ventilation with evaporative cooling.
- Surface mount service distribution systems.
- Integrate solar collection surfaces with roofs, walls and windows.

Energy conservation and manufacturing strategies:

- Engineer and manufacture houses in two tiers — 'structure' and 'infill'.
- Integrate manufactured, site-built and 'do-it-yourself' construction systems.
- Coordinate dimensions of sites, houses, rooms, components and energy systems.

Energy conservation and economic strategies:

- Design and manufacture energy systems to anticipate additions and remodels.
- Zone spaces for income generation apart from other spaces.

A Single Family Wood Composite Frame and Thin Insulation Panel House for a Cool Climate

Energy conservation and site design considerations:

- Apply passive heating and cooling strategies to constrained sites.

Energy conservation and house design considerations:

- Limit interior area and volume exposed directly to climate.
- Reduce heat loss and airflow at doors and windows.

Energy conservation and component design strategies:

- Differentiate structural frame from nonstructural insulating cladding.
- Increase the insulating and thermal storage capability of interior finishes
- Surface mount windows and doors.
- Improve the performance and convenience of movable insulation.
- Create thermal breaks at panel and frame connections.

Energy conservation and service system design strategies:

- Utilize concentrated mass passive heating strategies.
- Recover waste heat from appliances, exhaust air and water systems.
- Match electrical power source to end use.
- Surface mount service distribution systems.
- Optimize floor and roof cavities as chases and plenums.
- Improve flexibility of service distribution and connection systems.

Energy conservation and manufacturing strategies:

- Site assemble the house in a top-down continuous process.
- Coordinate performance standards among design, component and material options.
- Coordinate dimensions of sites, houses, rooms, components and energy systems.

Performance Specifications

Specifications were developed to quantify the projected and desired advances in computerized design processes, materials, components and manufacturing automation necessary to achieve energy efficiency in each design study. In this process the summary characteristics of both design studies were reconfigured as systems — groups of connected ideas or parts that act in concert to create or define a whole house — and refined in greater specificity and detail. Included were developmental studies and performance specifications in the following system areas:

Processes

- Manufacturing and Assembly

  A study to establish characteristics and performance indicators of a factory / field production strategy.

- Architectural and Engineering Design

  A study to establish characteristics and performance indicators of computer integrated sales, design, engineering and manufacturing processes.

Whole Building Performance

- Energy

  A study to establish energy loads and goals based on climate and use patterns. Subsequent envelope, mechanical and electrical system performance are evaluated against this performance standard. An energy goal of 'zero net energy use' (on a yearly basis, the house will at some time produce an amount of energy equal to its consumption from on-site sources) was established as the standard necessary to accelerate the process of innovation.

- Cost

  A study to establish cost parameters based on assumptions of projected costs for new materials, manufacturing and design processes and delivery mechanisms. Costs are aggregated in categories of directs costs (labor, materials, equipment), finished lot (acquisition and infrastructure), and indirect costs (supervision, field expenses, overhead, marketing, financing and income). An economic goal of 'zero net cost increase' (as a total of all cost categories) was established as the standard necessary to accelerate the process of innovation.

- Architectural Design
  A study to establish design performance indicators of function, market, spatial organization, design quality, appearance, siting, privacy and flexibility.
- Codes and Regulations
  A study to establish areas of conflict with representative building and zoning codes, and to to recommend necessary modifications.

Building Systems

- Structure
  A study to establish engineering characteristics and performance indicators of the entire structure, its materials, components and connections.
- Components and Materials
  A study to establish material characteristics and performance indicators of new materials and components anticipated or desired.
- Mechanical Heating, Ventilation, and Air Conditioning
  A study to establish engineering characteristics and performance indicators of alternative systems of heating, ventilating and air conditioning equipment that meet the stated energy goal.
- Water and Waste
  A study to establish input, output and performance indicators of alternate water and waste systems.

- Power, Lighting and Electronic Communication

  A study to establish engineering characteristics and performance indicators of power, lighting and communication systems including alternate luminaire designs, voltages and control systems over a range of occupancy uses.

- Dimensional coordination

  A study to establish dimensional matches between proposed and desired materials manufacturing processes, building assembly and construction processes, and, architectural and engineering design processes.

Future work

At this writing, a cycle of performance specifications has been completed and is about to be circulated for review. In parallel, we will conduct another series of design studies across a range of site and program assumptions. We will analyze each set of designs and evaluate the degree to which proposed performance specifications identified technologies, design strategies, and production processes that lead to marketable houses that are more energy efficient, of higher quality, and less costly. From that evaluation, we will develop a technical plan of short and medium term research objectives which will in turn generate proposals for research collaborations with industry.

Figure 1: Research Role of Design for Energy Efficiency Task

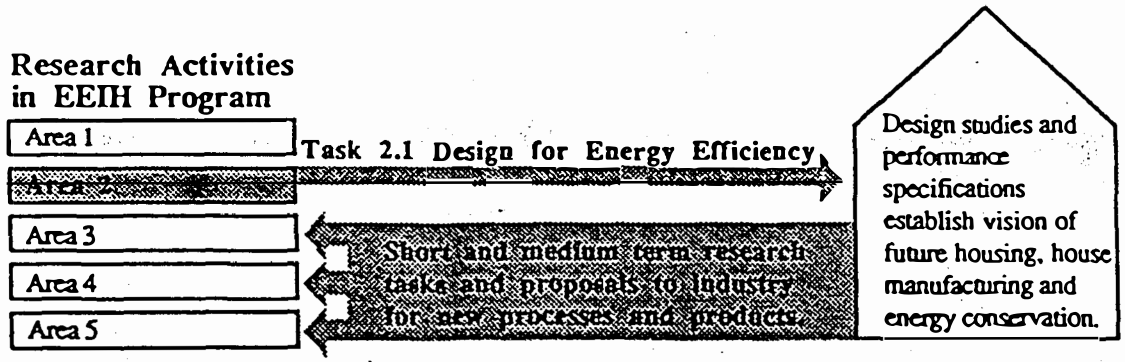

Figure 2 Overview of Stages in Development of Design for Energy Efficiency Task

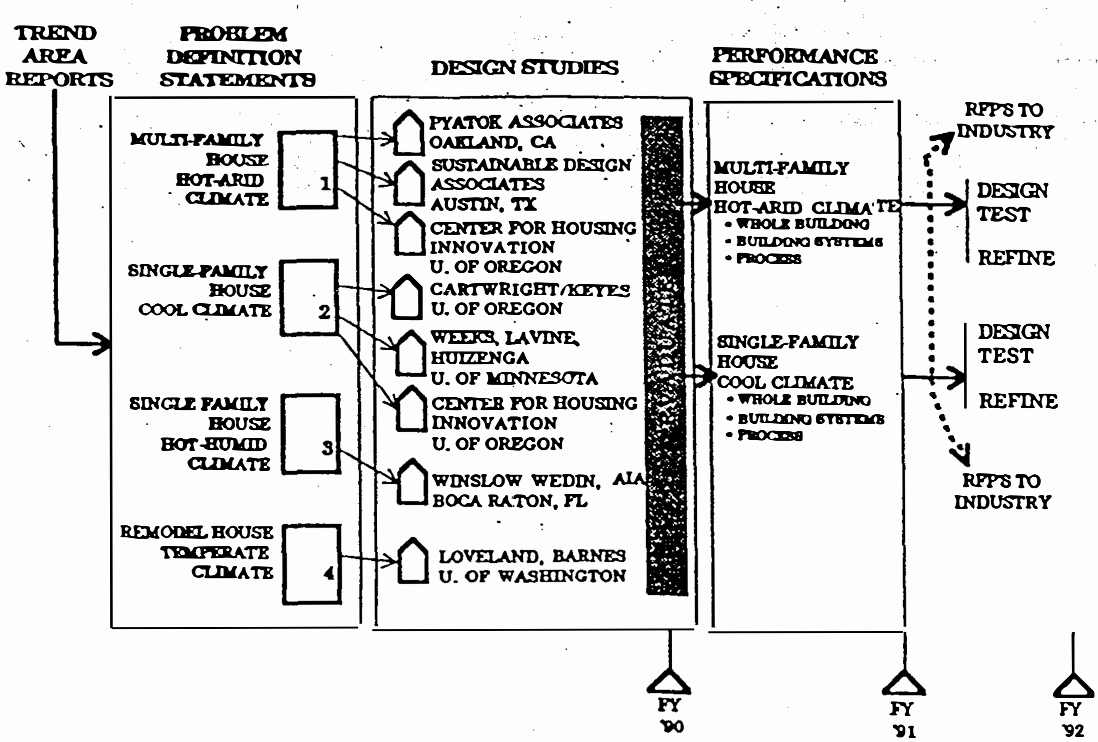

Figure 3: Axonometric of Site Plan, Starter House Design Study, Michael Pyatok Architect

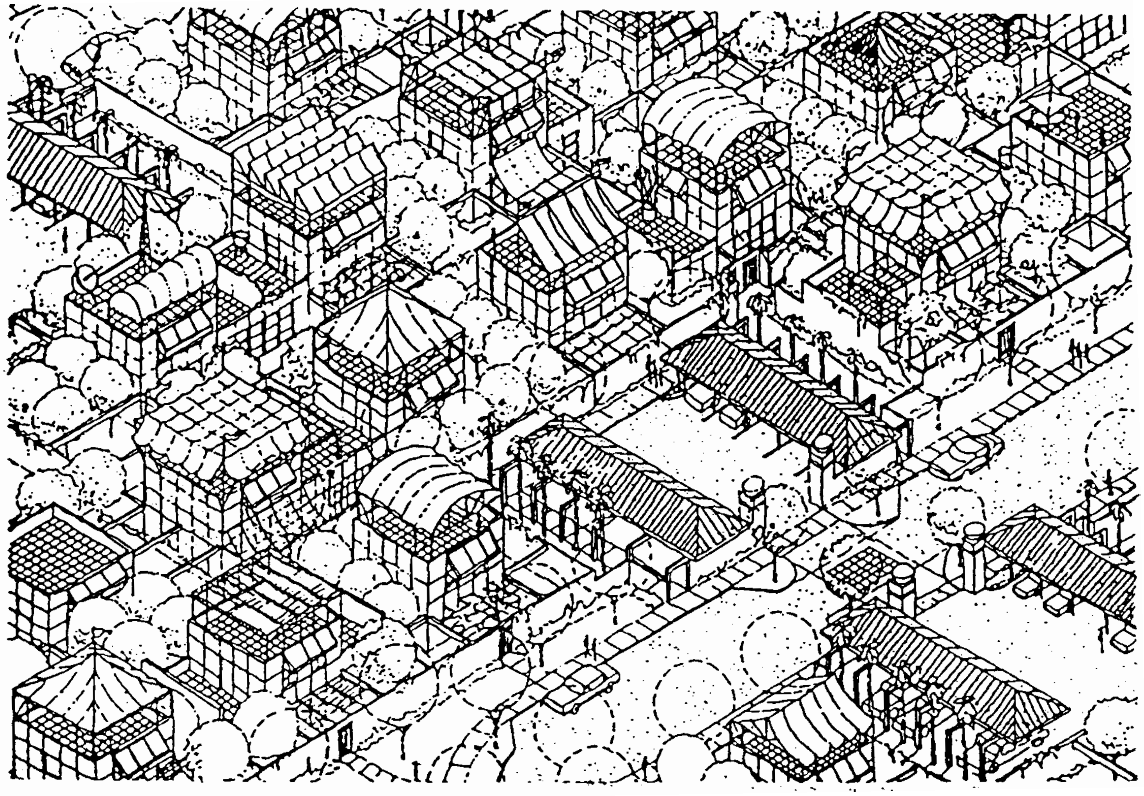

Figure 4 Axonometric of Site Plan, Extended Family House Design Study, Center for Housing Innovation

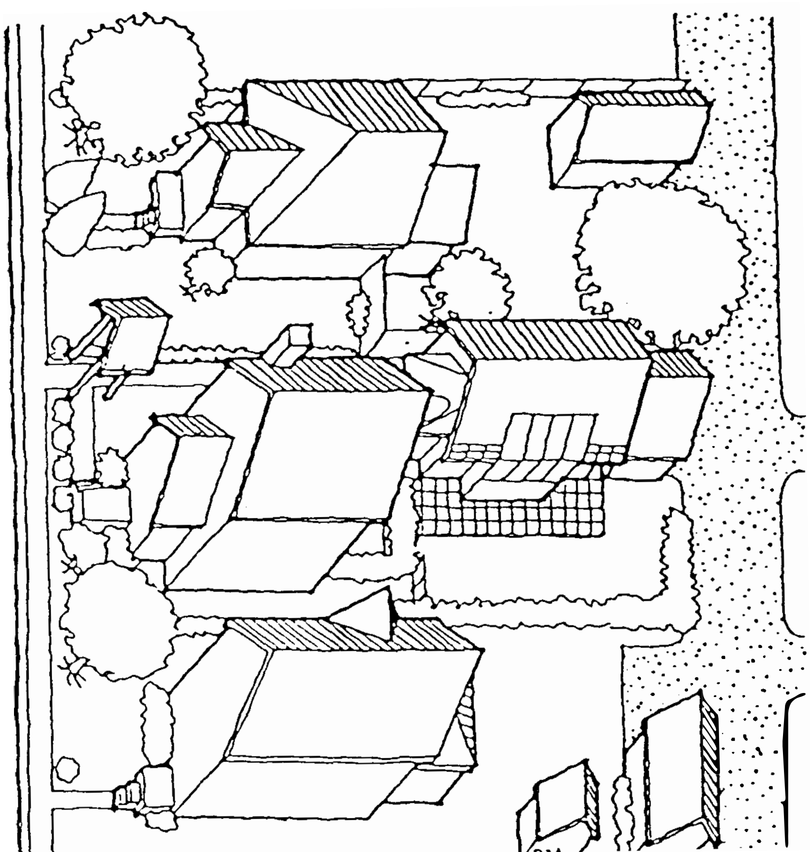

Figure 5 Perspective, Move-up House Design Study, Winslow Eliot Wedin Architect

Figure 6 Construction Strategy, Renewable House Design Study, Loveland and Barnes, University of Washington