THE ENVIRONMENTAL IMPACT OF PANELIZED SINGLE FAMILY HOUSING IN THE UNITED STATES

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The construction of single family housing in the United States is growing increasingly industrialized with panelization emerging as the dominant form of industrialization. Will this trend mean that housing construction, operation, and demolition will have more or less impact on the environment?

This paper analyzes differences between low levels of industrialization, such as site built wood framing or open wood frame panels, with higher levels of industrialization, such as closed wood frame panels, in terms of material use and waste generation in construction, and energy use in operation. An example of industrialization's impact on operational resources such as energy was demonstrated in an experiment using six units of housing built using various forms of factory fabrication — open wood frame panels, closed wood frame panels, and stressed skin insulating core panels. The tests showed that the more completely components are factory fabricated the better energy performance they have. In another experiment in which we constructed a single family house, we compared conventional on site construction (wood frame) to stressed skin insulating core panel construction. We determined that stressed skin insulating core panel construction used 5% less total wood and 50% less framing lumber.

These two examples show that high levels of industrialization can result in less environmental impact from construction and operation. However, in the case of panels, our survey of U.S. manufacturers indicates that there are a number of barriers to increasing the level of industrialization in panel manufacturing.

I. INTRODUCTION: THE CURRENT STATE OF INDUSTRIALIZED HOUSING IN THE U.S.

Valued at $179 billion in 1994, the housing industry in the United States has an enormous impact on the economy and environment [1]. The 1.6 million housing units constructed in 1995 (about 1 million of which are single family) consumed a large amount of raw materials and energy, and represent future demand for resources for operation and demolition [2].

Types of Industrialized Housing

Over the past 40 years, the production of houses has increasingly incorporated more industrialized components and processes, ranging from dimensional lumber, prefabricated walls, to completely prefabricated homes. The types of industrialized housing include HUD Code houses, modular houses, panelized houses, and production-built houses.

HUD Code Houses

A HUD code house is a movable or mobile dwelling constructed for year-round living, manufactured to the preemptive Manufactured Housing Construction and Safety Standard of 1974 (Figure 1). Each unit is manufactured and towed on its own chassis, then connected to a foundation and utilities on site. A HUD code house can consist of one, two, or more units, each of which is shipped separately but designed to be joined as one unit at the site. Individual units and parts of units may be folded, collapsed or telescoped during shipment to the site.

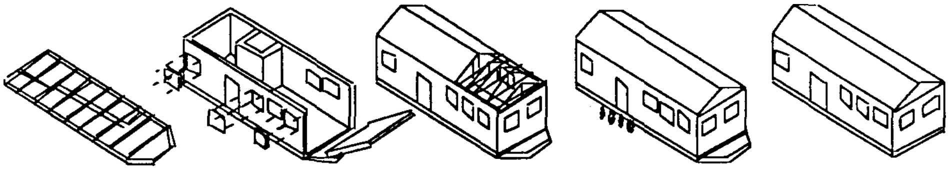

Figure 1: HUD Code House

Modular Houses

Modular housing is built from self-supporting, three-dimensional house sections intended to be assembled as whole houses (Figure 2). Modules may be stacked to make multistory structures and/or attached in rows. Modular houses are permanently attached to foundations and comply with local building codes.

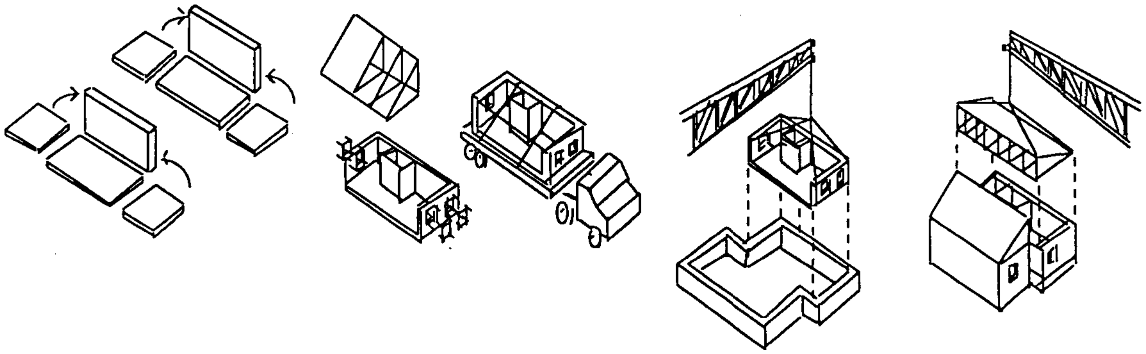

Figure 2: Modular House

Panelized Houses (includes domes, precuts and log houses)

Panelized houses are whole houses built from manufactured roof, floor and wall panels designed for assembly after delivery to a site (Figure 3).

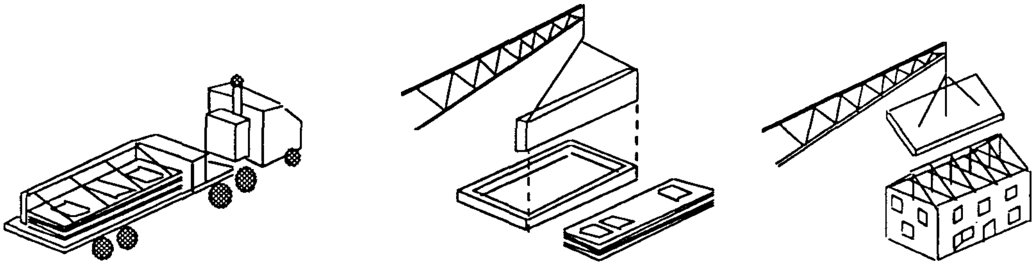

Figure 3: Panelized House

Production-Built Houses (includes those that use only a few industrialized parts)

Production building refers to the mass production of whole houses "in situ" (Figure 4). This industry segment is industrialized in the sense that it employs rationalized and integrated management, scheduling, and production processes, as well as factory-made components. In this instance, however, rather than the house being built in the factory and moved to the site the factory is the building site, which becomes an open-air assembly line through which labor and materials move.

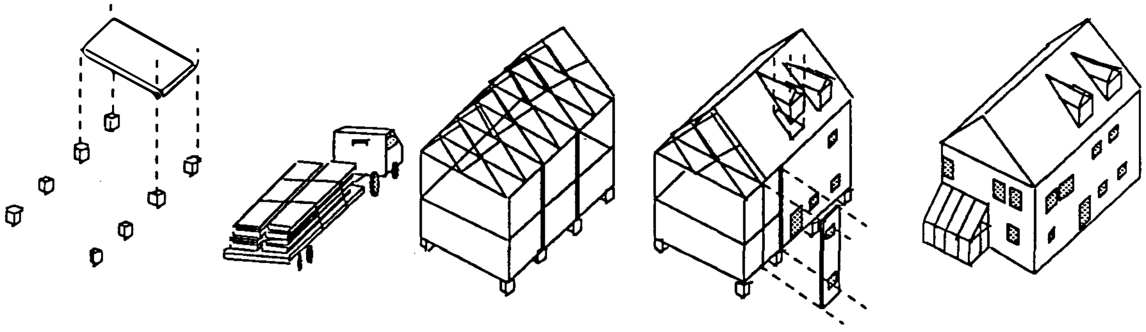

Figure 4: Production-Built House

Market Share of Industrialized Housing

Houses that are completely built in the factory are considered most industrialized and those built primarily on site as least industrialized. The last decade of industrialized housing production shows the growing strength of the more industrialized modes of housing. From 1985 to 1995, HUD Code, modular, and panel producers siphoned some of the market share from the less industrialized production builders (Figure 5). Panelized housing shows the largest increase in market share over this period, expanding from 37% in 1985 to 47% in 1995, and shows promise of increasing growth [4].

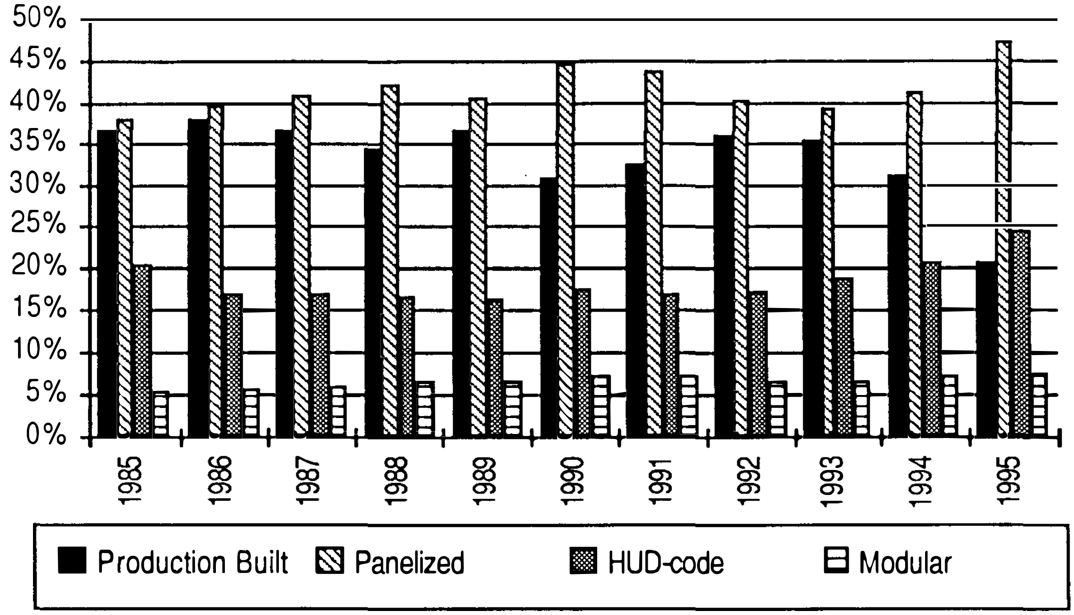

Figure 5: U.S. Housing Production by Market Share, 1985-1995 [5]

II. THE IMPACT OF RESIDENTIAL CONSTRUCTION ON THE ENVIRONMENT

The price of housing Americans can be measured in the effects upon the natural environment as well as by the economy. Houses impact air, water, and land quality, require raw material extraction, create waste and demand energy in operation. Transportation from home to office and shopping sends pollutants into the air — automobiles produce 43% of the total U.S. CO_2 emissions due to transportation [6]. Ground water provides 50% of the drinking water in the U.S., but more pavement and roofs means more rain water runoff (50% runoff in residential areas, 90% in urban), more storm water to treat, and less recharge of ground water [7].

Construction Material

The construction of houses requires a substantial amount of raw and manufactured materials which affect the balance of the environment. In the United States, a typical 194 m^2 (2085 sf) single family house requires 31 m^3 (13,127 board feet) lumber, 577 m^2 (6212 sf) sheathing, 12,685 kg (13.97 tons) of concrete, 216 m^2 (2325 sf) of exterior siding, 225 m^2 (2427 sf) roofing material, 194 m^2 (2085 sf) flooring material, 284 m^2 (3061 sf) insulation, 571 m^2 (6144 sf) interior wall material, 257 L (68 gal) paint/coatings, as well as doors and appliances [8]. The quantity and quality of trees in particular is greatly impacted by housing, since 90% of single family houses are constructed of wood. Single family homes create the largest single market for solid wood products in the United States. "In 1992 an estimated 41.3 million cubic meters of lumber, 9.0 million cubic meters of structural panels, and 3.0 million cubic meters of nonstructural were consumed in the construction of just over 1 million houses" [9]. Although currently annual tree growth is greater than harvest, current logging practices of road construction and clearcutting lead to erosion, irreplaceable loss of topsoil, and the pollution of rivers and streams [10].

The choice of material used in construction affects the degree of environmental impact. For example, when prefabricated panels are utilized as preserved wood foundation for basements, "the use of wood rather than concrete reduces the amount of embodied energy by about 30%" [11]. Concrete requires 1453–1589 kg (3200–3500 pounds) of raw material for 908 kg (one ton) of finished cement, produces CO_2, NO, and S gases, and requires 2344 MJ/m^3 (1,700,000 BTU/yd) of energy [12]. Wood, on the other hand, is a renewable resource, with low embodied energy, and shows promise of sustainable harvesting. In fact, wood uses the least embodied energy of any building element at 2.5 MJ/kg (639 kilowatt hours per ton). (For comparison, brick uses four times this amount, concrete (5x), plastic (6x), glass (14x), steel (24x), and aluminum (126x) [13]. Another example is the use of engineered lumber, which consumes less trees to fulfill the same structural function as solid sawn lumber. Lumber and timber consume half as much energy (7.38 MJ/kg) as veneer and plywood (14.62 MJ/kg) [14], yet the manufacture of engineered wood is highly efficient, using wood scraps and sawdust, so it actually saves trees. One manufacturer uses engineered lumber made from fast-growing trees like aspen or yellow poplar; the technology allows for use of "logs that are not large, strong or straight enough to be of structural value in conventional wood products" [15]. Three-quarters of each tree is used, reducing waste from using solid sawn lumber. A third example is the use of Oriented Strand Board (OSB) sheathing instead of plywood; OSB uses 59% less embodied energy as plywood, because it makes better use of wood fibers [16]. Using less trees and more wood means less impact on the environment.

Waste and Air Pollution

The act of building houses creates scrap material, bent nails, empty containers, and another waste products that require time, energy, and means of disposal, whether by recycling or landfill dumping. A typical 186 m^2 (2000 sf) home generates the following construction waste: Metals: 68 kg (150 lbs), Drywall: 908 kg (2000 lbs), Solid Sawn wood: 726 kg (1600 lbs), Vinyl: 68 kg (150 lbs), Engineered wood: 635 kg (1400 lbs), Masonry: 454 kg (1000 lbs), Cardboard: 272 kg (600 lbs), Containers (paints, caulks, etc): 23 kg (50 lbs), and 476 kg (1050 lbs) miscellaneous waste. This combined total of 3632 kg (four tons) of construction waste averages about $511 paid per house for disposal [17]. Wood products can account for 40–50% of residential construction waste stream. The U.S. is certainly not unique in this regard. In Canada, construction accounts for 16% of total solid waste (20% of this from new homes); 80% of waste goes to landfill. [18].

Besides raw materials and waste, another impact residential construction has on the environment is in the transportation of materials to the site. An estimated 20–25% of the total energy for construction is attributable to transportation, which contributes to global warming via carbon dioxide emissions. One fifth to one quarter of total CO_2 emissions are generated from the manufacturing of buildings. [19]

Operation

The composition and quality of construction of a house's exterior walls, roof and floors — the building envelope — substantially affects the energy consumption and cost over its lifetime. A Norwegian study found that the "energy use in buildings during the service life (50 years) accounts for more than 95% of the total energy consumption throughout the life of these houses." [20] Residential buildings account for about one fifth of the U.S. primary energy consumption, with 46% of this energy used primarily for heat and cooling [21]. Since energy consumption requires burning primarily fossil fuels, a more energy efficient house is kinder to the environment in the long run. Residences in the U.S. account for a third of the U.S. total electricity consumption, 57% of which is fueled by oil and coal. These fossil fuels produce CO_2, and other gases detrimental to the air quality and atmosphere.

III. COMPARISON OF PANELS WITH HIGH AND LOW LEVELS OF INDUSTRIALIZATION

The panelized housing industry encompasses the spectrum of levels of industrialization, defined as the degree of completion and/or complexity of a panel as it arrives on the job site. Less industrialized panels necessitate a moderate amount of finish work on the site, and more industrialized panels require little work on site. The most industrialized panels demand a factory setting for production. *Framed panels* can show low to moderate levels of industrialization, and are prefabricated components replicating traditional stick framing. These panels consist of dimensional wood studs attached to wood sheathing such as Oriented Strand Board (OSB) or plywood. Framed panels carry structural loads through a frame as well as the sheathing. Predominantly used are the less industrialized *open-framed panels,* which are sheathed on the exterior only and completed on site with vapor barriers, interior finishes, and electrical and mechanical systems. More industrialized are the *closed-framed panels*, which are shipped to the site sheathed on both the exterior and interior, and are sometimes pre-wired, insulated and plumbed. The most industrialized are the *stressed-skin insulating core panels,* which carry structural loads in the sheathing layers of the panel. These panels represent a new building component, that cannot be fabricated on site.

Fewer Trees Consumed with Stressed Skin Paneled House Construction

Evidence shows that housing built with the Stressed Skin Insulating Core (SSIC) panels consumes fewer trees compared to housing constructed with less industrialized panels. In an experiment conducted at the University of Oregon, the construction of a SSIC Panel Demonstration house was compared to that of a theoretical reference house of the same design and energy performance, but built with conventional on site wood frame construction. The SSIC panel house used only 5% less total wood, but 50% less framing lumber [22]. In another study, a stressed skin panel house and stick framed house, identical in plan, were constructed in a side by side comparison at the 1996 National Association of Home Builders (NAHB). The more industrialized stressed skin panel house consumed the same amount of sheathing material, but 26% less framing lumber (35.6 m^3 or 15,100 board-feet) compared to the traditionally constructed stick frame house (48.1 m^3 or 20,400 board-feet.) [23]

Using less framing lumber reduces the total number of trees required for the SSIC house and lessens the impact on the environment. Only 63% of a tree can be manufactured into solid lumber. However, more than 95% of a tree can be utilized when producing engineered wood and other composite wood products such as plywood and OSB. [24]

Reduce Waste with Panel Construction

Housing built with panels can reduce the amount of wood waste entering landfills, since panels use more engineered wood and are factory produced, centralizing recycling. In the SSIC house, the use of less framing lumber but more composite sheathing means that the SSIC house reduces wood waste compared to wood framed construction. Composite sheathing plants divert about 8.2×10^9 kg (9 million tons) of residual wood from North America's landfills every year. [25] Highly industrialized processes such as panel production benefit from the centralized function and economies of scale of a factory, especially when directing waste. "Materials which are assembled into finished components under factory-controlled conditions usually make more efficient use of resources, and disposal of waste from a factory is more easily controlled" [26]. When waste is centralized and consolidated, it is more likely to be recycled properly instead of buried in a landfill. "...The quantity of waste generated from a single house or group of houses may appear to be insignificant or less threatening to the environment" [27]. In NAHB's side by side test, the Stressed Skin panel house produced 76% less waste on site (3 m^3 or 4 yards) than the less industrialized wood framed house (13 m^3 or 17 yards), resulting in a savings of $325 in disposal fees [28].

A centralized production scheme reduces transportation. For example, a stick built house requires separate transportation of relatively small amounts of drywall, studs, and sheathing. A panel produced in a factory means larger shipments of these items, capitalizing on the economy of scale. The standard 1200 mm x 2400 mm (4'x8') size of panels originated as "the economical transport of a factory-built house suggested the dimensions of a standard trailer truck as a design criterion — the 2400 mm (eight foot) width being particularly crucial" [29].

Reduced Energy Consumption in Operation

Several studies show that the more highly industrialized the panel, the better the energy performance of the panel built house due to quality of insulation installation and thermal integrity of insulation type. One test performed at the University of Oregon compared the thermal performance of three housing units constructed with open wood framed panels, closed wood framed panels, and SSIC panels. The units constructed of closed panels and the SSIC panels were more airtight and had fewer thermal defects in wall insulation than the less industrialized open panels. The results indicate that a higher level of quality control is achievable in the factory when installing insulation. Insulation installed in the factory outperformed the site installed insulation, primarily due to missing or improperly installed insulation at the job site. The closed panel showed more heat loss through thermal bridging than the more industrialized SSIC panel [30]. In another study, two identical houses were built in Louisville, Kentucky, one constructed of Structural Insulated Panels (SIPs) and the other using conventional site built wood framing. The SIP house outperformed the wood framed house by 12–19%, mostly due to less loss from infiltration and thermal bridging. The air changes per hour (ACH) were measured at 0.21 ACH compared to 0.5 to 0.7 for a conventional house. [31].

IV. BARRIERS TO THE ADOPTION OF CLOSED PANELS

Housing built with more industrialized panels has less impact on the environment, yet only a small percentage of these panels are currently in use. The Energy Studies in Buildings Laboratory surveyed 363 panel building manufacturers [32] to assess the panel industry and the products being produced by panel manufacturers. A list of barriers to wood-framed closed panels was developed through discussions with selected manufacturers, field investigations of panel production, and interviews with building code officials.

Panel manufacturers were most often concerned with the profitability of a wood-framed closed panel and the potential market. Specific barriers included lack of flexibility in field installation of panels; codes and inspection requirements; construction trades; shipping and transportation of closed panels; lack of awareness of closed panels by builders/owners; lack of knowledge concerning required manufacturing equipment to move production from open to closed panels; and perceived loss of design flexibility

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