COMPUTER USE IN INDUSTRIALIZED HOUSING SALES, DESIGN AND MANUFACTURING PROCESSES

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ABSTRACT
This paper summarizes a study on the extent of computer use by industrialized housing producers in the U.S., Japan, Sweden and Norway. The study was directed at understanding industrialized housing production and energy decision making processes used by producers in order to set general criteria for new energy software tools and to make projections for future computer use in the industry.

Computers' first penetrations into the U.S. housing industry were in component design and manufacture. U.S. manufacturers continue to computerize an increasing number of discrete tasks such as drafting and material resource planning, aware of the difficulties in sharing data between individually automated tasks. Use of computerized energy tools by U.S. industrialized housing producers is low, though manufacturers recognize the need to automate as a means to increase productivity, improve quality control, and speed up communications between the various phases of production and management. As the number of software tools developed for the industry grows, so will the industries' willingness to accept computerization.

Japanese and Scandinavian companies are more sophisticated in their use of computers than U.S. companies - Sweden in the control of production and links between production and design, and Japan in the computerization of the sales process and its links to design.

Our analysis of the activities required to make a house and the nature of energy decisions revealed how critical it is to identify the correct audience to increase acceptance of computerized tools. This study concluded that energy calculations should be computerized and that the computer tools developed should be integrated with hardware and software systems expected to be used in the future by industrialized housing companies. Energy tools must be an integral part of any other computerized design and sales aids designed to be used with customers. New computerized energy tools should help link manufacturers of energy efficient products and homeowners. Energy tools should be part of expert systems which assist non-professional personnel in housing design.

1.0 INTRODUCTION

Since 1989 the U.S. Department of Energy has sponsored a research program organized to improve energy efficiency in industrialized housing. Two research centers share responsibility for the Energy Efficient Industrialized Housing (EEIH) program: the Center for Housing Innovation at the University of Oregon and the Florida Solar Energy Center, a research institute of the University of Central Florida. Additional funding for the program is provided by non-DOE participants from private industry, state governments, and utilities. The program is guided by a steering committee composed of industry and government representatives. One focus of this research is computerization in the industry.

This paper summarizes a study of computer use in industrialized housing (Brown et al, October 1990). The two objectives of this study were to: 1) review, assess and document the extent of computer use in marketing, design, engineering and manufacturing of industrialized housing, in order to compare and contrast the state of the art in U.S. vs. that in Japan and Western Europe; 2) assess and document the needs of the U.S. industrialized housing industry in order to establish design criteria for new computerized energy tools unique to this field.

This paper is organized in four major sections dealing with housing manufacturers' computer use in the U.S., Japan, Sweden and Norway; the decision making process that affects energy use in industrialized housing; projetions of computer use by the industrialized housing industry in the future; and general criteria for new energy design tools for the industry.

1.1 DEFINITIONS

Industrialized in our context implies 1) substituting machine for human effort in house building, 2) obtaining the economic advantages of volume buying, and 3) employing materials, tools and techniques different from traditional hammer-and-nails home construction. *Housing* as used in this study means privately owned one- to four-family dwellings. Housing can be divided into four major categories: HUD code (mobile) homes, modular houses, panelized houses, and production built houses. There are many hybrids of these categories.

HUD code (mobile) homes are the most recognizable U.S. factory produced houses. They are unique in that they are subject to a national preemptive building code administered by the Department of Housing and Urban Development (HUD). HUD code homes incorporate a frame on a chassis and wheels so they can be towed on the highway.

Modular houses are three-dimensional units built at a factory and moved to a permanent foundation at a residential site. *Panelized* houses arrive at the site as preconstructed wall, floor, and ceiling assemblies that workers erect and join together. *Production* houses are usually built in large numbers on tracts near metropolitan centers. Because production houses use a large number of factory made components (trusses, plumbing cores, etc.) and systematic management of construction sequences, their process is frequently referred to as "bringing the factory to the site."

2.0 COMPUTER TOOLS USED IN INDUSTRIALIZED HOUSING

There are many software packages on the market for the general fields of architecture, building, construction, and manufacturing. Some of these packages have potential applications within the field of industrialized housing.

2.1 METHODOLOGY

Information about the computer-based tools that are being used or are available to the producers of industrialized housing was collected from a variety of sources, including software directories, industry and research publications, and product literature obtained directly from a vendor. Firsthand knowledge of actual use was obtained during site visits and by telephone interviews.

Software directories were used to determine the extent of computerization in architecture, construction, and manufacturing fields. The most extensive software directories we found were: ASHRAE Computer Program Bibliography (Degelman, 1987) and the National Association of Homebuilders' Software Catalog for Home Builders (NAHB, 1989).

Books and articles on computer-aided design (CAD), computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM), artificial intelligence, and expert and knowledge-based systems were surveyed. Manufactured, prefabricated, and industrialized housing were joined as keywords with computers and several online computer databases were searched, but no new information resulted from that search.

Trade periodicals often compile directories in addition to providing articles and reviews of specific programs. Automated Builder published lists of computer-based tools in the January 1990 issue.

The literature and software search provided baseline information which was used to survey industrialized housing manufacturers. Manufacturers and associations were contacted by telephone or interviewed on site regarding their experiences with and degree of computerization. See Sections 2.3, 2.4, and 2.5 for abreviated descriptions of these firms.

2.2 A SOFTWARE TAXONOMY FOR THE BUILDING INDUSTRY

Eight basic software types were identified as being related to the building industry. A list of the categories and a brief description includes: 1) *Document Preparation*: programs used for production of text documents, including text with illustrations (e.g., word processors and specification writing programs); 2) *Data Manipulation*: programs used for input, computations, and output display. (e.g., spreadsheets and database management); 3) *Reference Data*: data files containing graphic or alphanumeric technical information (e.g., databases as for climate data, symbol libraries as for CAD, and subscriber networks); 4) *Graphic Tools*: programs for 2D/3D drawing, drafting, design, modeling; 5) *Analysis Tools*: programs used for structural, energy, finite element and other forms of numerical analysis; 6) *Manufacturing*: programs used for CAM, and numerical control; 7) *Integrated Systems*: programs which combine multiple uses (e.g., CAD/CAM/project management); and, 8) *Other Systems*: programs used for system overhead (e.g., modem software , terminal emulators, and networking).

In addition to the eight basic building software types, an expanded taxonomy of energy software was also generated. This taxonomy includes the following categories: 1) *Algorithm Base*: steady state, thermal network, ASHRAE Degree Days, etc. 2) *Applications*: heating, cooling, lighting, thermal performance/solar modeling, HVAC, energy accounting, and other; 3) *Loads, Energy Use*: component/zone/building, and hour/day/month/season/year; 4) *Design Phase*: concept, schematic, development, post design, and research; 5) *Output Report*: numeric and graphic; 6) *Input Data*: location, building type and schedules, occupancy rates, building area, etc.; 7) *Output Data*: load determinants, type of load outputs, and temperature; 8) *Documentation Format*: manual, HyperCard, video tape, and cassette tape; 9) *Input Time*: days, hours, and minutes; 10) *Typical Computer Response Time for Longest Operation*: days, hours, minutes,and seconds; 11) *Intended Use*: architect, engineer, technician, research analyst, builder, and home owner; 12) *Building Type to be Analyzed*: residential, commercial, and large commercial; 13) *Form of Climate Data*: hourly data, average data, and peak data; and, 14) *Hardware Required*: mainframe, minicomputer, microcomputer, and hand calculator.

2.3 COMPUTERIZATION IN INDUSTRIALIZED HOUSING IN THE UNITED STATES

Computerization in industrialized housing in the U.S. began with engineering software tools for component design and manufacture. Early examples include computer generated engineering calucations for truss design and progressed to automatic lumber cutting procedures, jigging, and truss plate attachment. A recent survey (Automated Builder, June 1989) found that 61% of the top panelized producers had CAD capabilities, with 24% of these also having CAM. Our survey of industry producers (including modular, mobile and panelized) reached a similar conclusion -- that manufacturers are beginning to automate portions of their work, especially in the areas of CAD/CAM.

We interviewed or visited manufacturers to determine their computer use. The complete survey included information on manufacturer type and computer software and hardware in use. The list of software types originating from the software taxonomy (Section 2.2) was used as a basis for data collection. Two manufacturers' computing environments are summarized here.

Shelter Systems Group (SSG), Hainesport, New Jersey, uses in-house software for design and engineering, manufacturing, material and resource planning, and cost accounting. Time and motion studies led SSG management to implement automation throughout company operations. This program includes a manufacturing facility which employs the Auto-Omni computer controlled saw for automated panel production.

Ryland, Columbia, Maryland, a producer of panels and modular units, uses computers to generate printouts of wall assemblies, as well as material lists which are used at the plant to guide assembly. AutoCAD and material and resource planning software is in use. Their main computer system is an HP3000.

Many of the manufacturers contacted had only recently begun to automate design and manufacturing due to the limited software available for their applications and the cost of education and equipment necessary to implement these programs.

2.4 COMPUTERIZATION IN INDUSTRIALIZED HOUSING IN JAPAN

Of the Japanese housing companies visited, Misawa, Sekisui House, and Sekisui Heim and are more completely computerized than any of the housing companies in the United States. All three companies claim to be moving towards increasing levels of computerization. Contrary to literature and folklore, we saw no computer systems that developed manufacturing data at the sales office, nor did we find any systems that integrated structural design or energy design with drawings produced by the CAD system. Energy analysis programs seem to be receiving minor use.

The system which is currently in use at Misawa's sales, design and manufacturing operations is a PC-based CAD system developed at Misawa. The salesperson develops the plan on paper with the customer, using sample plans and photographs. The design is input using a tablet and stylus. Given a plan, the software will calculate panel sizes. The system will check to see if floor panels have been mistakenly used for wall panels, etc. The user then selects the finishes from three groups, using either the Misawa products laser disk system, photographs, samples or a mix of these techniques. The computer prints material lists and develops the cost estimates for the customer. The dealer (an independent agent) then mails invoices to Misawa. This system is being upgraded to transmit information directly to the factory.

Sekisui House uses two different CAD systems -- one in the sales office and one in manufacturing. The sales system describes an architectural floor plan with wall locations, while the manufacturing system describes the components and panels which make up the walls and relative location to each other in an exploded, rather than architectural, view.

The CAD manufacturing system automatically draws the foundation, perimeter, and slabs for porches based on the floor plan, and the operator adds secondary structural members. The computer also draws the wall elevations and roof based on the plan. The drawings are returned to the sales office for review. They are frequently changed as customers refine their ideas. Once the drawings are completed, they are used to order materials and build the house. The data cannot be used directly for machine control. The CAD system used at manufacturing is a UNISYS-CAD running on a UNIVAC 1180/70. The plotter is a D SCAN XP1000.

Sekisui Heim, like Sekisui House, uses two CAD systems -- one for sales and one for manufacturing. In the sales area, the CAD system is used to draw perspectives of the house from the floor plan developed with the customer. The drawings are sent to the factory where they are redrawn in a form useful for manufacturing.

The manufacturing CAD system is McDonnell Douglas GDS 4.3, which runs on a DEC mainframe with Tektronix terminals. Sekisui Heim is also working on a system which integrates sales and manufacturing. The new system is expected to be intelligent in its ability to generate manufacturing information from sales drawings.

2.5 COMPUTERIZATION IN INDUSTRIALIZED HOUSING IN NORWAY AND SWEDEN

In comparison to the United States, Japan, Norway and Sweden all exhibited more sophisticated computer use in design, engineering, and manufacturing, with Sweden and Norway taking the lead in linking design with manufacturing and Japan linking sales with design.

Data Design Systems (DDS) in Sandnes, Norway, is a computer service company which originated as a spinoff from another of Norway's largest housing companies, Block-Watme. DDS has a relatively long history of computer use, starting with a mainframe computer and Danish AutoTroll CAD system in 1979. The new, PC-based system, now apparently widely used by other housing producers in Scandinavia, consists of a 3D CAD system and database as the central element, and nine other supportive software modules which can be purchased separately according the the users' needs. The modules include Arkpartner, Housepartner, Kitchenpartner, Interiorpartner, Terrapartner, Electorpartner, PreFabpartner, Buildingpartner and HVACpartner. The system uses a software package called ISPM to perform cost estimates.

The system can be seen as having three parts useful to an industrialized housing producer: sales, project documentation and manufacturing process. In the sales process, the CAD + Database + Housepartner are used to create a set of preliminary drawings including perspectives, bill of materials and cost estimate.

Nordisk Karto AB, a Swedish manufacturer of nails, screws, and glues has developed CAD systems for truss and house design. The software House CAD was developed with support of the Swedish Government and the support/cooperation of 20 house manufacturers. Their intention was to build a basic system which could be easily modified and enhanced for each manufacturer's needs. The resulting software was based on a Swedish CAD product called Varkon. It utilizes a Unix operating system and can run on a PC with a math co-processor but is often run on a mid-range machine with multiple graphic terminals.

For a given floor plan, the software automatically calculates the number of studs, plates, and headers and determines how they should be fastened, what their spacing should be and their order of assembly. This information is put into a file which is easily transferred to production control software. The program performs no energy calculations.

Insjöhus, a Swedish firm producing panelized houses, uses the Design Data Systems CAD software on a UNISYS computer and monitor and a Schlumberger (French) plotter. Insjöhus has developed very sophisticated estimating and production control software based on DAMAPS, which is an industrial engineering system. The software is about 40% standard and 60% proprietary to Insjöhus. It allows the user to build a very detailed description of each machine operation, labor time and material necessary to produce a given element.

Injöhus also uses a moisture program supplied by Gullifiber (an insulation manufacturer) to determine whether condensation will occur within a proposed wall construction. The user chooses a climate or inputs climate variables, and creates a wall by selecting wall elements. The software calculates the R value of the wall as pieces are added, and shows a temperature profile through the wall. The final output is a summary of moisture in the wall over the year. Insjöhus also uses an R value program supplied by Gullifiber to do the average R value check required by Swedish codes, but does not consider solar heating or mass in the building. The DDS software describes the areas required for input to the Gullifiber software.

Myresjöhus AB is the prefabricating home building company of the Myresjö group, which is comprised of Myresjöfönster (window and doors), Myresjökök (kitchens and wardrobes) and Combiglas (windows). Myresjöhus is one of the largest home producing companies in Sweden, with a plant capacity of 2000 units annually.

The Myresjöhus production facility includes a highly automated sawmill -- an example of a factory in which logs go in one end and houses come out the other. The wall and floor production lines at Myresjöhus were designed by Egil Borgersen of Karto, and he believes they are the most highly automated in the world. The wall panel assembly line is more automated then anything observed in Japan. There was automatic placement of insulation, studs, and window units and automatic nailing of sheathing and siding and interior finishes. This line was designed to produce the panels for 1200 houses per year (five per day). The operations of the line are entirely computer controlled with operations based on instructions developed during the process of producing CAD drawings. The CAD software is based on Medusa, developed by Computer Vision in Cambridge, Massachusetts, and now owned by Prime Computer. The software has been modified by Myresjöhus.

The CAD/CAM system does not perform cost estimating and it was unclear how connected it was to the inventory and ordering systems. The system also does not do the energy calculations which are required for all Swedish houses; instead a free-standing PC program called ENORM is used.

3.0 AN ANALYSIS OF THE ENERGY DECISION MAKING PROCESS IN INDUSTRIALIZED HOUSING

In order to understand where, when and by whom energy decisions are made in the housing process, we identified all of the activities involved in creating an occupied house on a site. Each activity was then evaluated as one in which an energy decision must be made or as one which sets criteria for an energy decision.

HOUSING ACTIVITY OUTLINE

I. The Physical House
- A. Land
  1. Identify Property
  2. Get Survey and Legal Description
  3. Transfer Ownership
- B. House + Site
  1. Clear & Excavate
  2. Build Foundation
  3. Build Frame
  4. Close In
  5. Install HVAC, Electrical, Systems
  6. Finish Interior
  7. Grade, Pave, Landscape
  8. Furnish

C. Components
  1. Make Panels
  2. Make Windows
  3. Make Equipment
  4. Make Furniture
  5. Etc.
D. Materials
  1. Make Concrete
  2. Make Lumber
  3. Make Shingles
  4. Make Gypsum Board
  5. Etc.
E. Result: House on Site Ready to Move Into

II. The Imagined House
  A. Idea
    1. Desire House
    2. Determine Financial Feasibility
    3. Determine Legal Feasibility
    4. Determine Architectural Feasibility
  B. Design
    1. Plan Site
    2. Do Schematic Design
    3. Do Design Development
    4. Do Working Drawings
    5. Design Interior
  C. Result: A Designed House

III. The Financial House
  A. Marketing
    1. Determine Image
    2. Promote Project
    3. Make Sale
  B. Capital
    1. Get Land Financing
    2. Get Construction Loan
    3. Get Loan Insurance Approvals
    4. Get Mortage
    5. Sell Mortage
  C. Result: A Buyer Ready and Able to Buy

IV. The Legal House
  A. Approvals
    1. Get Zoning Approval
    2. Get Plat Approval
    3. Get Preliminary Plans Approved
    4. Get Plan Approved
    5. Get Inspection
  B. Result: House Approved for Habitation

Most of the activities where energy decisions must be made occur within the Design area, since these activities define much of the physical character of the house. Most of the activities which set criteria about energy use fall in the Financial or Legal categories.

To assist our analysis of what types of energy decisions were made in each housing activity, we categorized energy decisions into six general groups. The six types are: *site decisions* (orientation, microclimatic variation, cluster shading, etc.); *morphological decisions* (building size and shape); *fabric decisions* (insulation level, window type, mass type, etc.); *equipment decisions* (type and fuel choice); *construction decisions* (how built versus how designed); and *operator / occupant decisions* (thermostat setting, occupant schedules and operable elements).

This analysis suggests that design tools should be directed at groups who have control over activities which contain energy decisions, and those tools should be specific to the decisions that group make. For example, compare a large HUD code producer to a production builder on the basis on one type of energy decision: siting. The HUD code producer has little control over the siting decisions since the decision is made by the purchaser, perhaps with the dealer's assistance. Therefore, HUD code manufacturers would opt for such energy conservation strategies as insulation and reduced glazing area, rather than those that are orientation-dependent like solar heating or summer shading. The production builder has comparatively more control over the siting decision. In the case of a speculative house, the builder alone makes the orientation decision. Thus energy design tools that deal with siting for HUD code homes should be directed at the dealer/customer, while similar tools for the production builder might be directed at the manufacturer/builder and used as part of the sales process.

4.0 THE FUTURE OF COMPUTER USE IN INDUSTRIALIZED HOUSING

The development of computer tools is a major investment of time and money. Once tools are in use they are difficult to change. In this section we speculate about what computerization in industrialized housing may be like in the future, so that tools developed now can remain in use long into the future.

4.1 TRENDS WITHIN THE COMPUTER INDUSTRY

The computer industry is projected to continue development of systems with increased capacity at less cost in all size ranges. Increased capacity means that memory consuming graphic systems and user friendly interfaces will become more feasible relative to size, complexity, and speed, while decreased cost will make systems more prevalent in larger companies and within reach of smaller companies' limited budgets.

Networking has and will continue to provide collective computing power that will facilitate efficient resource allocation and the ability to work on exceedingly complex projects which involve business management, materials and resource planning, factory floor operations, design, engineering, inventory, sales and marketing.

Extensive research is being conducted at universities in the development of expert systems, computer modeling, and robotics, with applications in manufacturing and construction (Pohl, 1989). Successful research in these areas should lead to applications in industrialized housing.

Finally, increased computer literacy in the workplace coupled with continued development of user friendly interfaces sets the stage for computerization of tasks not previously accomplished on a large scale.

4.2 TRENDS WITHIN MANUFACTURING, CONSTRUCTION, AND INDUSTRIALIZED HOUSING

"The recognized decline in the productivity of many U.S. companies over the past 15 years has been a strong stimulant for individual companies to search for ways to improve their operational efficiency and to become more competitive in the market place." (Flautau, p. 60). This trend is mirrored in the industrialized housing industry where computer usage is on the increase as manufacturers look for ways to make their products more competitive.

Research in the field of industrialized engineering is focusing on the manufacturing process from business functions to design to inventory control. Because they emphasize engineering, many of these firms have already embraced computing in some aspect of their manufacturing process.

The U.S. housing industry is becoming increasingly industrialized (Brown et al, December 1990, p.13). In the process, housing production is becoming more standardized and rationalized. Both standardization and rationalization make automation easier than environments requiring random or complex instructions.

4.3 SCENARIOS FOR INCREASED COMPUTERIZATION

Current trends in computing and manufacturing will result in increased and more sophisticated computer use within U.S. industrialized housing companies. This change would have several potential impacts on the design process and the house.

4.3.1 Scenario one: Supplier Model

There is growing dependence on manufactured products such as windows and trusses in the construction industry. Some aspects of this industry have been computerized. Product data from electronic catalogues, often using CD-ROM or electronic networks, specifications, engineering calculations, material takeoffs and CAD interfacable files, aid the designer and builder in integrating the product with the design process and production. This aspect of computerization has yet to reach full potential for use or integration. This software will become more prevalent and sophisicated, perhaps containing expert systems to assist the designer.

4.3.2 Scenario two: CAD/CAM Vendor Model

Existing integrated CAD/CAM software systems which already perform routine engineering calculations and material takeoff will become more inclusive, linking design to production and sales. A major obstacle has been the lack of integration of isolated computerized process steps and the creation of a cohesive, automated whole from design concept through product delivery. If these systems are integrated in an effective manner, the benefits will be increased speed of production and improved product quality. These systems, for which key components of future development will be machine control, artificial intelligence and robotics, will be applicable from factory to production builders.

4.3.3 Scenario three: Japanese Model

Large companies will develop in-house software to integrate one or more of the major functions of marketing, design, management and production. This approach is currently being pursued by NV Ryan.

Production will become more automated in terms of machinery utilization or instructions to skilled laborers, which will be electronically integrated with design -- reflecting a greater need to handle increased information about design variability on the factory floor than a need for increased productivity.

5.0 CRITERIA FOR COMPUTERIZED ENERGY DESIGN TOOLS FOR INDUSTRIALIZED HOUSING

The purpose of this section is to describe general criteria for new computerized energy design tools based on our assessment of computer use within the industrialized housing industry and several scenarios about future computer use.

There are three basic approaches to integrating energy tools with software currently in use in the industry. First, add energy features to existing CAD software (e.g., AutoCAD). Second, add energy features to existing industrialized housing software (e.g., ICG, Truss Star and DDS). Third, add industrialized housing features to existing energy software.

The first approach is difficult because most CAD systems describe only lines, not building assemblies like walls. Therefore the system doesn't recognize and store any of the building element information necessary to determine energy performance. Second, adding energy features to existing tools requires the cooperation of those vendors, and the systems must describe the building completely. There are currently only one or two systems which describe the building completely in terms of its thermal elements. Third, adding industrialized housing features to existing energy software also requires the cooperation of vendors, if the software is not in the public domain. This approach requires the development of the features of industrialized housing software. There are several hybrids from these basic categories which merit exploration.

In addition to tool market integration, a few general criteria apply to the development of the energy tools. In order to be used, energy tools must be linked to audiences who benefit from energy savings. The first group of those who benefit are homeowners. Thus the tools should work well in the house sales process and in the stages of home design in which owners typically participate. The link between energy use and home design is strong, and most manufacturers feel that enabling owners to participate in the design of their houses is an important sales feature.

The second group that benefits from energy savings are manufacturers of energy saving products. An example of this product type is the structurally efficient stressed skin panel based on a energy efficient polystyrene core. Tools should be developed for these manufacturers because they are already motivated to sell energy efficiency. If possible, the tools should link the energy efficient product manufacturer directly with the homeowner via the home builder.

Research and development energy tools are intended to do sophisticated modeling of building performance. Many manufacturers do not have the personnel qualified to operate these tools. Design tools, in contrast, demand less knowledge of the thermal performance of buildings and no programming knowledge. Their primary users are design professionals, sales personnel, and homeowners. The purpose of these tools is to allow the user of the software to manipulate known building elements (i.e., windows) and understand their impact on building energy use.

Because energy decisions are made throughout the process of creating a house, many non-energy decisions are interdependent with energy decisions. For example, the decision to increase window areas and change orientation for view is also an energy decision. Energy tools should help the user see these interdependencies and work with them to optimize the housing design.

The most advanced proprietary systems in use by industrialized housing companies are already beginning to develop "expert" parts. Given the extensive research and development that is currently taking place in expert systems and the potential savings in manufacturers design time, it is likely that expert systems will characterize software used by industrialized housing companies.

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