PATH

Partnership for Advancing Technology in Housing

Technology Roadmap: Whole House and Building Process Redesign

Year One Progress Report

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve quality, durability, environmental efficiency, and affordability of tomorrow's homes.

PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, all federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA). State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

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Prepared for:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
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NAHB Research Center
Upper Marlboro, Maryland

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About the NAHB Research Center

The NAHB Research Center, located in Upper Marlboro, Md., is known as America's Housing Technology and Information Resource. In its nearly 40 years of service to the home building industry, the Research Center has provided product research and building process improvements that have been widely adopted by home builders throughout the United States. The Research Center carries out extensive programs of information dissemination and interchange among members of the home building industry and between the industry and the public.

Disclaimer

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FOREWORD

This document, *PATH Technology Roadmap: Whole House and Building Process Redesign*, is one in a series of technology roadmaps created to serve as guides to help the housing industry make decisions about research and development investments.

The Partnership for Advancing Technology in Housing (PATH), administered by the Department of Housing and Urban Development, is focused on improving the affordability and value of new and existing homes. Through public and private efforts, PATH is working to improve affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation, and labor safety. To accomplish this, PATH has identified research and established priorities for technology development that will enable the home building industry to work toward the PATH mission. This priority setting process, known as "Roadmapping," has brought together many industry stakeholders, including builders, remodelers, trade contractors, material and product suppliers, financial representatives, codes and standards officials, and public sector R&D sponsors. To date, the group's work has led to the development of three technology roadmaps: *Information Technology to Accelerate and Streamline Home Building*, *Advanced Panelized Construction*, and *Whole House and Building Process Redesign*.

This document focuses specifically on taking a whole house persective on home building and refining the building process. The vision for this Roadmap is to "Build Better Homes Faster and at Lower Cost." The document describes the situation today. It also details industry challenges, and outlines activities and accomplishments that will lead to the achievement of the vision. These include managing the change process, creating an environment that facilitates systems solutions, industrializing the home building process, improving the constructability of houses, and moving more of the home building process into the factory.

By addressing these issues through research, the home building industry will continue to play a key role in providing affordable, durable housing for America's families.

Lawrence L. Thompson
General Deputy Assistant Secretary for
Policy Development and Research

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PATH PROGRAM GOALS

The Partnership for Advancing Technology in Housing (PATH) advances technology in the home building industry to improve the affordability and value of new and existing homes. Through public and private efforts in technology research, information dissemination, and barrier analysis, PATH is adding value to seven of the nation's key housing attributes: affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation, and labor safety.

As such, three overarching goals have been established that all bear on those attributes:

- **To determine the needs for improved housing technology development and provide relevant strategic services.**

  PATH will investigate the institutional barriers that impede innovation; will propose alternative, improved, or negotiated services to overcome those barriers; and will develop networks and agreement among participants to implement these services.

- **To develop new housing technologies.**

  PATH will support and perform technological research at all R&D levels of the home building supply chain with governmental and industrial funds and resources.

- **To disseminate new and existing technological information.**

  PATH will coordinate dissemination of innovation information (both for specific technologies and for industry-wide technological information) that remains unbiased, technically accurate, and relevant to specific housing audiences to increase the familiarity with, availability, and use of technologies in the home building and homeowner communities.

Partners in the PATH program—the U.S. Departments of Housing and Urban Development (HUD) and Energy (DOE), the Environmental Protection Agency (EPA), the Department of Agriculture (DOA), the Department of Commerce, the Federal Emergency Management Agency (FEMA), home builders, researchers, and manufacturers of building materials and products—have long recognized the importance of injecting current and emerging technologies into the home building process. The PATH program has identified many of the relevant technologies and has facilitated implementation of research, pilot, demonstration, and evaluation projects across the United States. In addition, PATH program partners recognize the importance of planning research and setting priorities for technology development that will enable the home building industry to work toward the PATH mission. This priority setting is known as "Roadmapping."

ROADMAPPING PROCESS

The objective of PATH technology roadmapping is to identify technology areas for immediate technological research in home building to serve as a guide for research investments by government and industry. The PATH Industry Steering Committee (ISC), comprised of builders and manufacturers of building products and materials, oversees the development of all technology roadmaps.

As the primary planning activity for PATH's research, the roadmaps dictate the main areas for research and development in PATH's research portfolio (which includes background, applied, and development activities), as well as provide the home building industry with a strategic plan for future technology development. Roadmaps approved by the PATH ISC will be provided to private sector interests to guide their technology development and to the government to guide its investment in research and development. Through this process, new technologies and additional research work will be generated as the roadmaps are implemented.

The ISC initiated the roadmapping process during the first quarter of 2000. A group of 40 builders, materials and products suppliers, academicians, researchers, and other stakeholders identified and rank ordered technologies that hold the promise of guiding PATH's research. The ISC then assembled the technologies with the highest potential benefits into three technology portfolios as follows:

- *Information Technology to Accelerate and Streamline Home Building;*
- *Advanced Panelized Construction; and*
- *Whole House and Building Process Redesign.*

The PATH ISC recommended development of technology roadmaps for each of the three areas, with *Information Technology* initiated in November 2000, *Advanced Panelized Construction* in December 2000, and *Whole House* in March 2001.

The roadmapping reports are available on both the PATH website (www.pathnet.org) and the NAHB Research Center's ToolBase Services website (www.toolbase.org).

This report deals specifically with *Whole House and Building Process Redesign.*

VISION

Simply stated, the vision for this Roadmap, *Whole House and Building Process Redesign*, is to "Build Better Homes Faster and at Lower Cost." The vision continues:

By 2010, home design and construction is efficient, predictable, and controllable with a median cycle time of 20 working days from groundbreaking to occupancy with resulting cost savings that make homeownership available to 90 percent of the population.

Homebuyers are pleased with their purchases because their homes have many of the benefits of custom houses yet cost less, have fewer defects, are more durable, and have lower operating and maintenance costs than the equivalent houses of 2001.

Builders and subcontractors maintain or improve margins by reducing costs and selling more homes.

This will be achieved through improving the whole house design and the manner in which a house is constructed using new and innovative products, systems, processes, and education.

The current situation in the home building industry, especially as it relates to the design of homes and the process by which they are built, is summarized below.

Home is More Than Just a Place to Live

The home is the centerpiece of the typical American family. In 1999, over 66 percent of American households owned their own home. Homeownership is an important way for Americans to accumulate wealth—home equity accounts for more than half of the total net worth of the typical homeowning family. The importance of the home to the American family may well be the reason that homebuyers usually want personalization or customization of their home. It should be different from all the others. This personalization is in opposition to some of the fundamentals of industrialization and productivity improvement—that is, to "standardize," to maximize the number of common elements and subsystems, and to minimize the variety of components. Although some manufactured housing is comparatively affordable, it often does not meet the expectations of consumers for personalization.

Homes are Becoming Less Affordable

Unfortunately, houses are becoming less affordable for Americans. A recent NAHB analysis of Department of Commerce statistics indicates that the median cost of houses increased 32 percent from 1992 to 1997, while the median salaries increased only 24 percent. While the durability of houses is open to debate, the perception that houses are less durable is persistent. For home builders, the challenge of building affordable, durable homes becomes ever more challenging as the labor pool shrinks and the costs of materials and land development increase.

The Home Building Industry is Extremely Fragmented

As a business, the home building industry remains highly fragmented and is typified by small builders managing many small trade contractors. According to "Structure of the Residential Construction Industry" (Gopal Ahluwalia and Jo Chapman, NAHB Housing Economics, October 2000), the 1997 Census of Construction shows the following:

- In spite of mergers and acquisitions, the number of residential contractors grew from 131,000 in 1992 to 145,000 in 1997. The data shows that about 46,000 of those 145,000 contractors did remodeling only, which leaves a total of 99,000 contractors who built approximately 1.2 million units. That averages to about 12 units per builder.
- The data further indicates that 73,500 builders built less than 25 homes, but accounted for 39 percent of the homes built. Builders in this category have an average of only four employees on the payroll. Builders who built less than 100 units accounted for another 21 percent of the houses and had an average of eight employees on their payroll. This means that 60 percent of the total houses built are built by companies who build less than 100 houses per year and have an average of less than eight people on their payrolls.

Home Builders are Faced with an Enormous Management Challenge

As indicated by the small number of employees in a home building firm, the vast majority of home builders place little reliance on in-house labor crews. Instead, they focus on meeting customer needs by orchestrating the labor of a host of subcontractors and dealing with a wide range of suppliers and third parties. Accordingly, they manage and oversee not only key activities carried out within the firm, but also the activities of subcontractors and other participants in the supply chain. The management of key activities affects schedule, costs, prices, and profitability, as well as performance of the end product. Good management of the home building process can easily make the difference between success and failure in a highly competitive environment.

Coordination of the work of these independent subcontractors is very difficult. Most of the construction is performed at the job site where the process and the materials are subjected to the vagaries of weather. Weather delays ripple through the numerous subcontractors resulting in rescheduling nightmares. Theft and vandalism are two other ever-present problems that result not only in the cost of replacing the materials, but also in schedule slips and complex rescheduling. In short, the home building process is inherently difficult to control.

Use of Processes and Tools to Improve Productivity is Not the Norm

The application of processes and tools for productivity improvement in home construction is the exception rather than the rule. Except for large volume builders and producers of manufactured homes, the majority of home builders today use tools and processes that have been around for decades. In general, builders do not address the house as a product amenable to processes used by other industries that might improve productivity and reduce costs in home building. This is especially true for site-built houses where the processes may be somewhat more challenging to apply. Few site builders have adopted processes such as just-in-time (JIT) or lean construction, and few are using information technology tools to improve their productivity.

It may not be surprising that builders do not usually treat the house as a system because the residential construction industry in general does not treat the house as a system. Architects and designers typically design houses that are aesthetically appealing and functionally complete. Rarely is the designer connected to the constructors in the same way as manufacturers in other industries connect to their designers and producers. In other industries, concurrent design is used, where the people responsible for manufacturing the product, testing it, and supporting it in the field are an integral part of the design team. Lack of a systems process creates problems not only in building affordable houses, but also energy efficient, durable houses.

Whole House, Systems Thinking is Just Emerging in the Industry

The needs and opportunities for whole house approaches to home building are now recognized by a number of individuals, companies, and organizations in the industry. Examples of current activities and products are summarized below:

- The Build America Program—five research consortia of manufacturers and building science entities in the United States and Canada—is looking at the building envelope and all the components that go into that as a system, instead of as individual parts, that must work efficiently together.

- Owens Corning, in a program called "Systems Thinking," includes siding, insulation, windows, and roofing claimed to work together as a system, optimized for cost, function, and performance.

- A variety of affordable designs and products developed for third world countries show real innovation, such as:

  DuraKit's Instant House is built from triple-corrugated, ¾" treated cardboard. The houses assemble in one day with three unskilled workers and cost around $13 per square foot.

  Another company, Moladi, uses recyclable plastic forms and poured aerated concrete. The homes can be "framed out" (forms set, pour completed, forms removed) in about two days.

  Robust Home, touted to be a total building system, is offered for use in third world countries by an alliance of companies who claim that a steel-and-concrete house can be built by three men in only 10 days.

- House_n: The MIT Home of the Future, is a multi-disciplinary research project at the Massachusetts Institute of Technology focused on how the home and its related technologies, products, and services should evolve to better meet the opportunities and challenges of the future.

- Optimum Value Engineering (OVE) looks at the framing process as a whole and optimizes the use of materials and reduces labor cost for documented savings of $500 to $1,000 in material costs, and three to five percent in labor costs.

- The MADE (Marketable, Affordable, Durable, Entry-level) Homes project focuses on: Expandability/Flexibility; Curb Appeal/Marketability; Affordability; and Durability.

  Key components are a flexible, open living area, expandable rooms, modest footage, modular dimensions, lot configuration, strategic window usage, OVE framing techniques, stacked bathrooms, porches, and overhangs.

- Plumbing manifold/tubing systems by Vanguard and Kitec reduce labor cost by simpler installation compared with conventional plumbing processes.

- A "Super Assembler" study was conducted to develop a broader category of worker called assembler. The assembler position, seen as a growing future need, would likely require fewer skills, thereby opening potential employment to a broader pool of people.

- A study, "Industrializing the Construction Site," being performed by Virginia Tech for HUD Policy Development and Research investigates methods for industrializing the job site.

Conditions that are perceived to be barriers, challenges, or gaps along the way to achieving the vision stated on page 3 are summarized below.

Systems Engineering and Systems Analysis

A general lack of systems engineering and analysis in the design and construction of homes pervades the industry. Homes are typically designed with a heavy emphasis on aesthetics, but with inadequate attention to what will make the home less costly to build, or what will improve durability and energy efficiency in the climate in which the home will be built. To date, the home building industry has lacked the resources and impetus to establish the collaborative efforts necessary for this important discipline. Comments from the roadmapping group include:

- There is a fragmented approach to regulatory enforcement.
- Not enough systems engineering is used in the design and production process.
- There is no systematic design analysis, especially with integrated systems.
- Very little R&D is going on in the housing industry. Technical progress in systems analysis and integration is slow.
- Residential building science typically is not used.
- No well-funded advocate of the systems approach has emerged in the private sector. This may be due to lack of potential profit.
- Homes are not designed and laid out for efficient use and low cost.
- Materials and components are not designed for fast build or integration.
- Specialty licensing is needed for trades and designers.

Consumers and Marketing

Because a home is by far the largest single investment most families will make, resale value is of critical importance. Yet, it is not evident that consumers or the industry have a clear picture of what value in housing is. Whether the home building industry is consumer driven is debatable, but generally it is assumed that consumers demand homes that are personalized or at least give the appearance of customization. Also, consumers seem to believe that bigger and different are better, and that modular, panelized, or other variations where much of the construction is done in factories are inherently of lower quality. Comments from the roadmapping group are provided below:

- Consumers expect more choices in housing than the industry is able to give them because builders sell customers on the concept that their houses are easily customized.
- To consumers, faster construction implies lack of quality.
- Consumers believe bigger is better.
- Consumers do not understand the need for flexible, adaptable space (one of the concepts that could improve affordability).
- Buying decisions in new houses are related to potential resale value.
- There is no definition of values and what the industry is striving for.
- Consumers are not educated on technical issues. Consumer perceptions of value are variable and non-standard.
- Very little J. D. Power type of consumer satisfaction data exists, which means the industry does not have a good measure of what consumers want.
- Housing is the last bastion of "custom." Everything else is mass-produced.

- Affordable customization and personalization options are needed.
- Basic options are not priced for high volume acceptance to yield cost savings.

Labor

Labor remains an important factor affecting the cost and quality of homes. Labor can be a factor in the resistance of the industry to change, as unions are typically not motivated to change. The educational process does not facilitate the implementation of new technologies, as relevant vocational education is not available in many areas. Comments from the roadmapping group included:

- Insufficient qualified labor is available to meet the needs of the industry.
- Labor and craft unions are resistant to new systems and materials and not motivated to streamline the labor process.
- Relevant vocational education is lacking in many areas of the nation.

Regulatory Process

The regulatory process can impose significant cost penalties in the construction process, as plan review, permitting, and inspections can cause time delays and bottlenecks. Application of new technologies is often delayed by the approval process because inspectors and local code offices are reluctant to approve products or materials with which they are not intimately familiar. Even after the evaluation services of the national code bodies (BOCAES, SBCCIESI, ICBOES) or the National Evaluation Service have evaluated a new technology, the multitude of jurisdictions across the country accept the new technologies at different times. Even when the new technology is written into the code, there may be local variations or non-uniformities that make cost-effective implementation difficult. Comments from the roadmapping group include:

- Permitting, codes, and inspections slow the process.
- Government over-regulation leads to excessive costs.
- Too many and non-uniform rules complicate standardization, as does the fragmented industry structure, which is slow to evolve.
- Regulatory issues and codes drive up costs.
- Manufacturers often do not address testing, codes and standards reviews, and compliance until very late in the product development cycle or even after the product is in production.

Builder Resistance to Change

Builders often resist using new technologies in their products. Risk is a big factor. Horror stories with past technologies such as barrier-type EIFS give them ample reason to be skeptical. The fact that they rely on subcontractors to do the work means they must convince a sub to use the new technology, and then assure that the sub's employees have the training and skill necessary to use the new technology. Often builders have inadequate examples to emulate—that is, who else has tried a technology and what is the formula for success? Comments from the roadmapping group include:

- Future liabilities discourage innovative products and processes.
- Builder ability to change is limited because of limited resources.
- Often prototypes or examples are not available to show the way.
- Manufacturers do not provide adequate training on installing new products.
- Builders and contractors work independently and are isolated from each other.
- Cost of change is an issue to manufacturers and builders. They need to find answers to questions like: *Do I have to invest? Will it self-fund? Will someone invest?*

- The industry focuses a lot of attention on small builders who typically are not able to affect change. Focus is on the mass in the middle rather than those on the leading edge.

Builders' Lack of Control of the Home Building Process

Builders, especially the small ones, lack control of the home building process. They rely on a multitude of subcontractors to do the work. Scheduling these subcontractors is extremely difficult, and accommodating the ripple-through effect when one of the subcontractors does not complete on schedule, when the weather causes delays, or when materials are not delivered on schedule, is a nightmare. Although information technology has the potential to significantly improve the situation, most builders do not use it because they lack the capital and/or the knowledge. The fact that construction takes place at the job site makes the application of information technology even more difficult. Comments from the roadmapping group include the following:

- Weather and climate impede cycle-time improvement.
- Effective production management and process planning are lacking.
- ERP systems are all very different, mostly difficult to use, and most builders lack understanding of how to use them.
- Many builders lack an understanding of how to use information technology.
- Houses take longer to build than they should. There are too many variables to lay out and control a schedule.
- Many information and communication gaps exist in the home building process.

Industry Lack of Collaboration and Resistance to Change

The home building industry in general has not shown the collaborative spirit of some other industries, such as automotive, steel, and electronics. There are few horizontal alliances across manufacturers, distributors, or builders, and few vertical alliances of manufacturers and distributors and builders. It is not clear what causes this shortcoming—the fact that the industry has been on a sustained upswing, the lack of offshore competition, the lack of evidence that collaboration or alliances will result in increased profitability, or other causes. Comments from the roadmapping group include:

- Little organized collaboration exists among stakeholders in the industry.
- The industry has not defined its values or goals.
- The biggest impediment to change is that the profit in change is often not evident.
- The industry waits for crisis before it changes.

Industry Fragmentation

The industry is fragmented and appears to be getting more so. The number of residential contractors grew by about 10 percent between 1992 and 1997. Many of these are small builders with very low capital. While many of these builders build quality homes, they typically cannot afford to implement information technology, which may be necessary for their economic survival. Additionally, the current situation that permits starting a home building company with almost no capital funds allows those who have limited knowledge of the science of home building to label themselves "home builders."

Not only the builders and general contractors are small. Much of the construction is performed by an array of equally small, similarly under-capitalized trade contractors—roofers, insulation installers, drywall installers, plumbers, electricians, HVAC installers, painters, and so forth.

Home Quality is an Issue

The quality of the homes built in this country is not as consistently high as it could and should be. An article in the *Boston Globe* on April 29, 2001, with the headline, "Luxury by Design, Quality by Chance," shows how a large, national builder with a good reputation may have significant quality issues. Although the article overstates the problem, quality by chance is too frequently encountered in the industry. The quality problems are a result of factors including inadequate systems engineering in the design of the product, inadequate management controls on the job site, effects of weather on the components, inadequate skills of installers, quality and durability problems in products and materials, and others. Financial incentives for building quality homes are lacking. There is currently no link or a very weak link between the quality of the home built and the ability to finance and the cost to insure. The only real financial incentive is reducing callbacks, although there are also efforts underway that encourage builders to use quality as a marketing tool. Comments from the roadmapping group include:

- Materials and processes need to be more weather tolerant.
- Current onsite practices create quality problems.
- There is no link between the quality of the product and the financing and insurance process.
- Current systems as installed are often lacking in quality, e.g., HVAC ducts, house wrap, and flashings are too often incorrectly installed.

ROADMAP

OVERVIEW

Five strategies for positively affecting *Whole House and Building Process Redesign* were agreed upon and are detailed below. The first two are not technology research and development projects. They are strategies for proactively dealing with two issues that are well known and frequently lamented in the home building industry: extreme slowness in adopting innovative, new technologies, and the absence of systems science and engineering in the manufacture of building products and in designing and building houses. In the collective judgement of the PATH *Whole House and Building Process Redesign* roadmapping group, these two barriers must be overcome in order to have any chance of achieving the PATH goals.

The five strategies to advance *Whole House and Building Process Redesign* and the benefits of undertaking each strategy are:

1. **Manage the Change Process: Accelerate Acceptance of Innovative Home Building Technologies.** The key stakeholders in the home building industry must establish and manage a well-described framework for influencing and speeding the process of adopting the new technologies needed to achieve PATH goals.

   Benefits

   ✔ Will significantly reduce the time required for new technologies to be accepted in the home building industry. This reduction will make it possible to achieve PATH goals.

2. **Change the Home Building Paradigm: Create an Environment that Facilitates Systems Solutions.** Recognizing that the fragmentation of the industry requires collaboration and alliances to apply systems sciences to designing and building homes, create an environment that encourages working together.

   Benefits

   ✔ Will convert the industry from non-communicating, inward looking producers of house components, to a set of vertical and horizontal alliances of stakeholders addressing the house as a system.

   ✔ Will result in centers of excellence that will perform systems research and will train architects, engineers, and technologists in systems analysis and engineering.

3. **Industrialize the Home Building Process.** Apply manufacturing processes and technologies, many of which have already been proven in other industries, to achieve higher levels of production efficiency.

   Benefits

   ✔ Will achieve construction (manufacturing) efficiencies currently realized by many of the best manufacturers of cars, airplanes, and other system products, while providing the customization demanded by homebuyers.

   ✔ Quality of homes will be significantly higher because the process will be controlled.

4. **Improve the Constructability of Houses.** Develop the system science and perform analysis and engineering that will make houses easier to construct, will reduce labor content, will reduce materials cost, and will improve quality, durability, and safety.

   Benefits

   ✔ Mechanical systems will be disentangled to ease installation.

   ✔ Mechanical and structural systems will be integrated to improve durability and function and reduce cost of materials.

   ✔ Houses will be designed to be easy to build, reducing labor costs and errors in construction.

5. **Move More of the Home Building Process into the Factory.** Perform more of the building process in a factory where it is easier to control the process and to use information technology and robotics.

   Benefits

   ✔ Standard module sizes and interfaces will allow for construction of compatible modules by different builders, thereby reducing cost but enhancing customization (hence marketability).

   ✔ Required job site labor-skill needs are reduced to assembly.

   ✔ Modules are easier to transport and are not damaged during shipment.

   ✔ Modules are easier to put in place and assemble as a result of improved foundation quality.

All of the benefits above convert to affordability and/or quality of the resulting product. In addition, ability to customize is significantly improved for any given price point. Each strategy is further detailed in the following sections.

1 MANAGE THE CHANGE PROCESS: ACCELERATE ACCEPTANCE OF INNOVATIVE HOME BUILDING TECHNOLOGIES

The Whole House working group decided that one of the breakout groups would focus on the management of the change process because it was common to all of the substantive roadmapping efforts. The home building industry is characterized as slow to adopt innovative new technologies. Fifteen to 20 years to mean acceptance of an innovation is considered normal. Given this scenario, an innovation brought to market today would not expect full market penetration until 2015 or beyond, which exceeds the 2010 end point of the PATH program.

The breakout group set out to determine if there is a way to accelerate the acceptance of new technologies into the building process so that manufacturers will realize more rapid returns on their R&D investments, thereby giving them more incentive to invest in additional R&D toward next generation product development and process improvement. The group discussed how to develop a model approach to managing the change process for new technology development and introduction.

An important book regarding this process is *Diffusion of Innovation* by Everett Rogers. He suggests that factors influencing a decision to adopt include: Relative Advantage; Trialability; Compatability; Observability; and Complexity.

In regard to building, three additional practical factors that must be considered are: Profitability to the Builder; Patentability for the Manufacturer; and Code Acceptance.

The *Diffusion of Innovation in the Home Building Industry* by Burt Goldberg (NAHB Research Center, November 1989) utilizes the methodologies developed by Rogers to examine several case studies of innovations in the home building market. Goldberg and Charles Field are presently utilizing expert industry panels to examine factors leading to the acceptance of wood I-joists and Exterior Insulation Finishing Systems (EIFS) in the building market.

The Roadmap for implementing this strategy is summarized in Figure 1 and discussed further below.

1.1 Create a Process Working Group

Create a process working group consisting of leaders from key stakeholder groups. They are to conduct or have conducted the analysis of commercialization, consider linkages, develop an action plan, act as the monitors of the change efforts, serve as outreach to stakeholders, and see to the development of tools to assist in commercialization. In order to create this group, the first step is to identify principal stakeholders (e.g., PATH/ISC members, government agencies, manufacturers, distributors, academia, and regulatory groups) who would logically be included.

Once identified, the group should meet to define member roles, rules governing its process, its strategic plan for facilitating the adoption process, and so on.

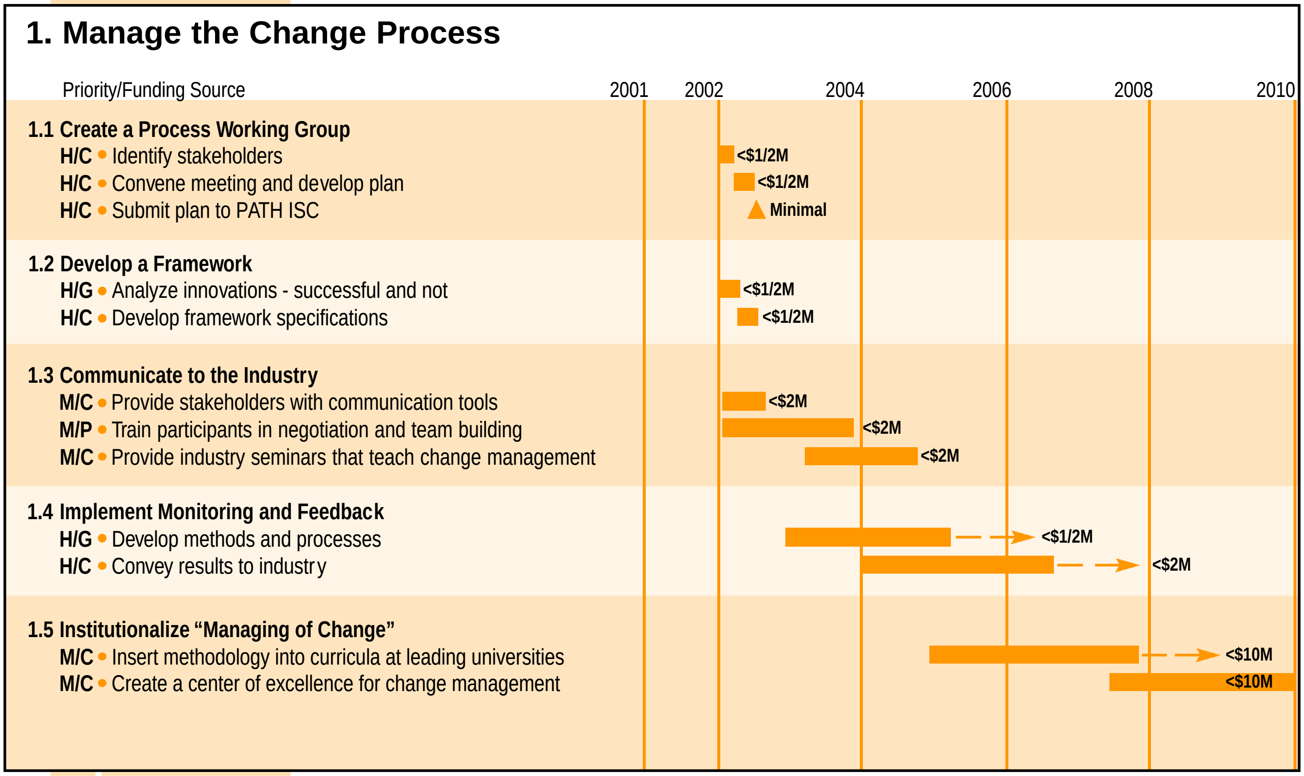


Figure 1

Key: Priority: L, M, H = Low, Medium, High
Funding Sources: G, P, C = Government (public), Private Industry, Combination
Funding amounts are approximations.

1.2 Develop a Well-Described Framework

Develop a well-described framework for influencing the adoption process that meets the goals and objectives of fostering the rapid introduction of new technologies in housing. The framework would address the myriad of challenges faced in introducing products, from training practitioners through obtaining code acceptance at the national, state, or local level, whichever may be feasible given the technology in question. This framework would produce a detailed technology acceptance plan that could be implemented by one or more companies that are introducing the technology.

The first step in developing this framework is to analyze innovations that have either successfully been commercialized or experienced difficulties (e.g., the work being done by the NAHB Research Center in its analysis of EIFS and wood I-joists). From that point, those involved can develop the framework specifications.

1.3 Communicate to the Industry and Others

Even the best ideas can be lost if not adequately communicated. In order to make sure the building industry and others know about progress in this aspect of the roadmapping initiative, the stakeholders need the proper tools to communicate and partner effectively.

To further the collaborative nature of this venture, participants must be trained in negotiation and team building skills.

Ultimately, there should be industry seminars that teach change management methodology that can be put into practice.

1.4 Implement Effective Mechanisms for Monitoring and Feedback

As the communication strategies come into play, it is important to remember that one-way communication can have limited effectiveness in this type of effort. Methods and processes for monitoring progress must be developed in order to learn and provide feedback to others. Monitoring would include a systemic understanding of the process, tracking the process in different efforts in order to revise and update the "framework," sharpening available tools, and tracking specific technical efforts. Stakeholders should then convey these results to the industry through appropriate outreach tools.

1.5 Institutionalize the "Managing of Change" Approach in Academic Curricula

The working group determined that a powerful way to promote the managing of change approach is to introduce the concept into the curricula of business and engineering schools at leading universities.

The group also thought it would be worthwhile to create a center of excellence for change management that will provide resources and guidance to technology insertion activities.

Key Development Milestones

The group agreed that a white paper should be prepared in the near term for distribution to key stakeholder groups which would focus on practical steps PATH might take to accelerate the commercialization process with respect to housing innovations. The paper would consider the literature on the diffusion of innovation and extract lessons from other current industry efforts.

The group also agreed to initiate a diffusion working group and initiate a focused project (analysis, linkages, action plan, understand how to motivate change, assess the monitoring, outreach to stakeholders, develop tools, etc.) on creating and managing a change model.

2 CHANGE THE HOME BUILDING PARADIGM: CREATE AN ENVIRONMENT THAT FACILITATES SYSTEM SOLUTIONS

A theme repeated many times at the roadmapping session, and generally across the home building industry, is that we need, but are very deficient in, system thinking. System thinking addresses the overall design as well as selection and assembly of compatible components to achieve an affordable, durable, energy efficient, and safe system—the home provided to the American consumer. The lack of system thinking is in dramatic contrast to the automobile and aerospace industries where system design and engineering are fundamental to production of their products. Yet, the home is an extremely complicated product that is expected to last for 10 or more times as long as a car or an airplane.

Why does the home building industry lack system thinking? Probably because the industry is unique. It is comprised of many very small builders. And most builders, large and small, are dependent upon a host of subcontractors, over whom the builders have little control. This is in stark contrast with automakers who have almost total control over all of their suppliers. The typical manufacturer of home building products makes only a few of the components going into a home. A window manufacturer, for example, typically is not going to devote much attention to the total system that is a house.

In the auto industry the system thinking is done by GM or Ford, and in aerospace by Boeing or Northrop-Grumman. Can we expect builders to perform in a similar fashion? Even production builders have very limited resources compared to the giants in the other industries, and the "typical" builder—who builds 20 homes a year and has less than 10 employees—is relying on his personal knowledge and skill, possibly with the help of a site supervisor.

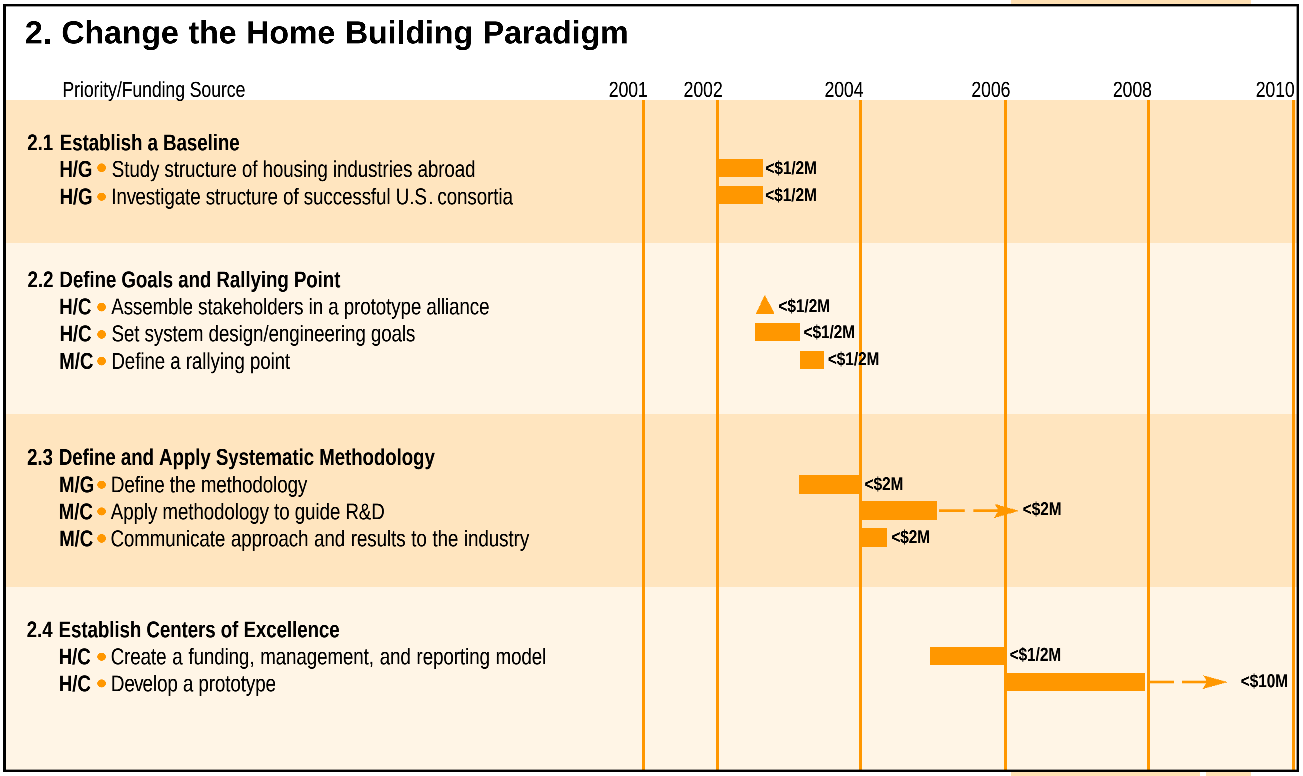
To solve this problem, the industry—researchers, manufacturers, home designers, builders, trade associations, and others—must work together. The industry must collaborate and communicate, form alliances, forums, and associations that will stimulate, encourage, and sponsor application of systems sciences to the design and production of homes and of the products and materials that go into those homes.

Strategic alliances of suppliers and end users must be formed to address the system design and production issues that need solutions in order to achieve significant progress toward the PATH goals. Both horizontal and vertical alliances and collaborations are needed. Horizontal alliances would be formed to address products, groups of products, or subsystems, such as windows or HVAC systems or trusses and panels. Vertical alliances would cut across the various stakeholders in the home building process, such as designers and architects, builders, trade contractors, manufacturers, and distributors.

The strategies for implementing this part of the *Whole House Roadmap* are shown in Figure 2 and described in the accompanying text.

2.1 Establish a Baseline

While making strides to change and improve the building process, the roadmap working group was not motivated to “re-invent the wheel.” The group encourages the building industry to look at models in other industries and/or other countries.



Key: Priority: L, M, H = Low, Medium, High
Funding Sources: G, P ,C = Government (public, Private Industry, Combination
Funding amounts are loose approximations

Figure 2

They suggest studying the structure of the housing industries in Europe, Japan, and Australia where successful alliances or consortia are functioning both within the industry and between industry and government.

Another suggested avenue is to investigate the structure of successful industry consortia in the United States in other industries (e.g., the Microelectronics and Computer Technology Corporation or the Software Productivity Consortium) to find a model that seems appropriate. The way the auto industry works seems irrelevant, given the industry is controlled by a few giants. The mission of the Software Productivity Consortium is: “To serve its members, affiliates, and the national interest by providing highly leveraged system and software technology and services to increase productivity, profitability, and competitiveness.” A similar mission might be appropriate for a Housing System Consortium.

2.2 Define Goals and a Rallying Point

With the baseline established, stakeholders should be assembled in a prototype alliance. Stakeholders need to be from a vertical slice of the home building industry, with multiple players from each sector (e.g., manufacturers, designers, builders, trade contractors, etc.). The alliance should be focused on achieving a well-defined goal within a specified period of time. This might be the demonstration of a new manufacturing process or of the application of a process existing in another industry to the home building process.

Certainly the PATH goals for affordability, energy efficiency, environmental performance, durability, and safety serve as the guidelines for research and development. However, stakeholders in the residential construction industry who are involved in this prototype alliance need to set goals they want to achieve in the arena of system design and engineering.

The alliance would then define a rallying point—a tangible, visible symbol that encourages and demonstrates system thinking. An example may be "FutureHome," a European commission supported project for creating high quality housing. The following quotes are taken from the FutureHome website.

[FutureHome] aims at developing techniques, technologies, and systems for affordable, manufactured housing in Europe, taking into account the diversity of styles, designs, and materials, as well as the preferences of the customers.

The main deliverables of the project are expected to be:

- *Enabling technologies for development of high quality and low cost housing.*
- *International database of organizations and companies related to the construction market segments.*
- *Research towards new software for housing design and production (CAD/CAM).*
- *New production and assembly techniques for building components.*
- *Use of automation in onsite and off-site processes.*
- *Development of finishing and fitting technologies.*

House_n: The MIT Home of the Future is another example of an approach to stimulate research and creative solutions.

2.3 Define and Apply a Systematic Methodology for System R&D

An alliance or consortium of stakeholders needs to accept responsibility for defining, funding, and overseeing the necessary system research and development. This group would use a systematic approach to make informed decisions that consider risk, benefits, timing, and available funding. The consortium might use a dual-pronged approach with one prong focusing on evolutionary or incremental improvements and the other focusing on revolutionary change. The evolutionary focus might lead to demonstration factories, projects, and houses that would provide scale-up assessment of their concepts, and which could be economically introduced in a shorter timeframe. The revolutionary focus might lead to "concept" factories and houses that may not be currently economically viable but would push the state-of-the-art, similar to how automotive racing teams develop technology years ahead of incorporation in typical passenger cars. Implementation would offer a spectrum of options that would allow builders to mix and match elements of technology ranging from purely stick-built to completely modularized.

The steps involved in this process would include:

- Developing a systematic methodology for managing the paradigm shift;
- Applying it to guiding R&D projects and investments; and
- Communicating the methodology and its results to the industry via the PATH program and other communication channels.

2.4 Establish Centers of Excellence for Housing Systems Sciences and for Industrializing the Home Building Process

Various centers of excellence would be formed to develop and examine technology concepts in a number of specific areas to overcome obstacles identified. These might be housed at universities, but should include academics, researchers, designers, manufacturers, and builders to create, develop, and test manufacturing-efficient concepts, designs, and processes.

Centers of excellence might be established in various technology areas of interest, such as: system analysis and design; system testing in the laboratory and field; robotics and information technology for the job site; robotics and information technology for home building factories; designing homes to make them more producible; panelization and modularization; and change management for technology deployment.

Required activities include:

- Creating a funding, management, and reporting model. Funding for these centers would come from a variety of sources including federal (and hopefully state) governments, manufacturers of housing products and components, and larger builders; and
- Developing a prototype center of excellence targeting a specific technology area of high interest and potential payoff to the industry. This prototype will serve as a learning tool and a model for additional centers.

3 INDUSTRIALIZE THE HOME BUILDING PROCESS

Industrialization of home building has two important goals. The first is to improve the efficiency with which the home is built. As depicted by the curves on the left in Figure 3, production or factory-built homes typically are built with more efficiency than site-built, custom homes and therefore have less need for improvement. The second goal is to improve flexibility of changing home designs to suit customers' needs. In this case, custom homes already have quite a bit of flexibility, but factory-built homes need significant improvement as shown in the curves on the right of Figure 3. If the industry is successful in implementing the strategies in this Roadmap, both efficiency and flexibility will be significantly better no matter where the homes are built, nor in what quantities.

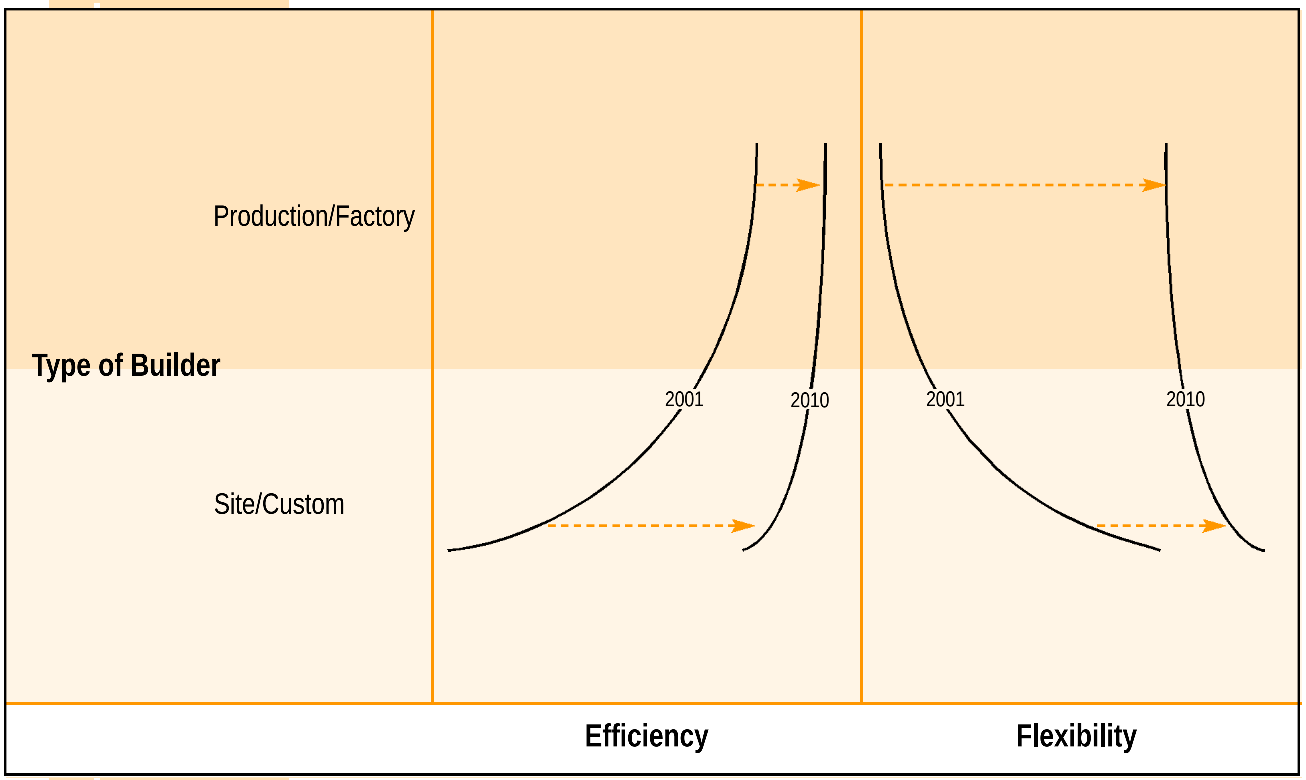


Figure 3

The thrust of this industrialization activity is to apply manufacturing processes and technologies, many of which have already been proven in other industries, to achieve higher levels of production efficiency by:

- Finding or creating environments that offer more control;
- Substituting capital (e.g., robots) for labor; and
- Properly using products and materials. (Note: This is further addressed in section 4.3, Designing Houses for Producibility.)

In summary, the intention is to make construction of a house more like manufacturing—increasing efficiency and improving quality control and safety.

The Roadmap for implementing this strategy is shown in Figure 4 and described below.

3.1 Apply Manufacturing Processes to Home Building

Adapt and apply manufacturing processes that have been successfully used in other industries to the process of home building. Address factory-built, modular, panelized, and stick-built homes.

A study performed by Virginia Tech for HUD, "Industrializing the Residential Construction Site" (O'Brien, Wakefield, and Beliveau, July 2000), provides an excellent overview of what is going on in the home building industry in the United States and abroad, as well as manufacturing concepts successfully used in other industries.

Industrialization concepts that have worked in other industries and that currently may be in use by production builders need to be considered. Examples include:

- Just-in-time (JIT) manufacturing that includes effective supply chain management. Although the supply chain management that works well for GM is not applicable to individual small builders, several of those builders may form alliances to gain leverage. (Supply chain management is addressed in the *Information Technology Roadmap*.)
- Flexible, agile, lean production systems.

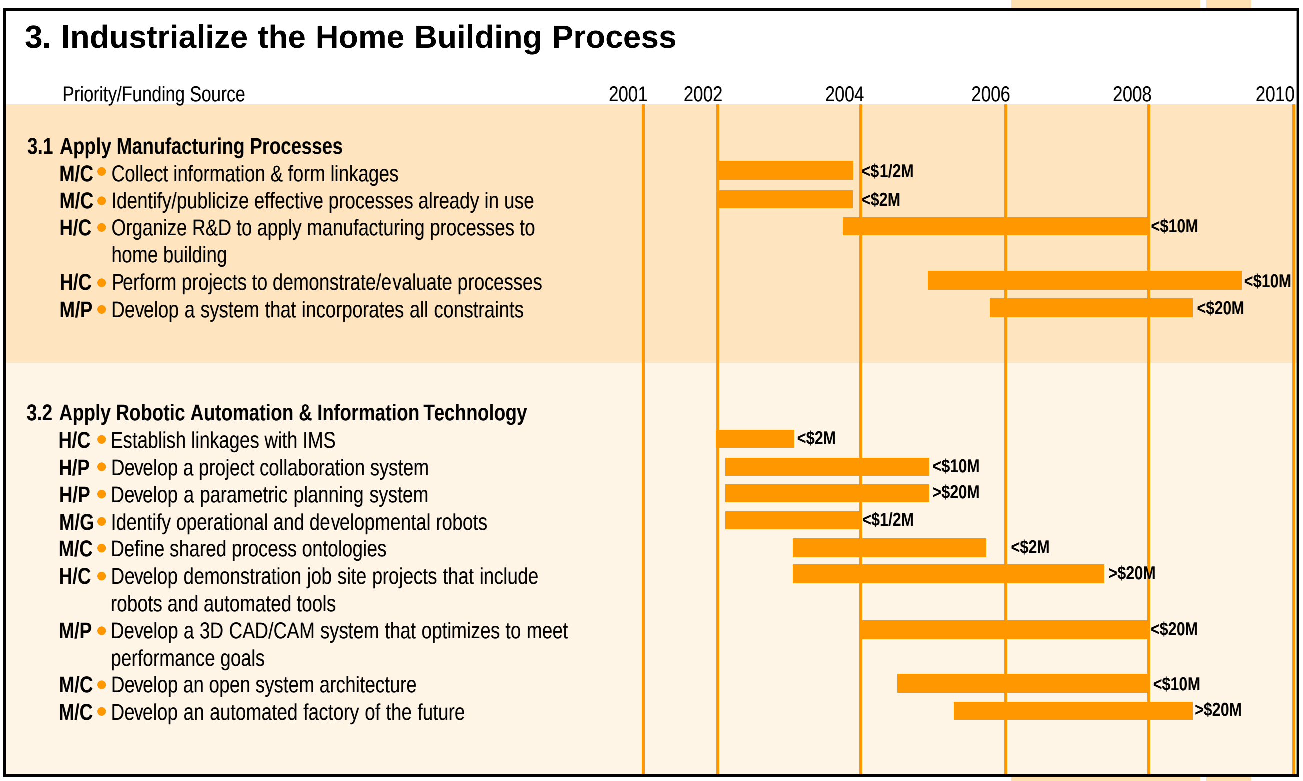


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Figure 4

- Concurrent engineering and design for manufacturers that use various techniques and processes to enhance the manufacturability of the product.
- Manufacturing requirements planning (MRP), manufacturing resource planning (MRP II), and enterprise resource planning systems (ERP), which are processes that are enabled by information technology.
- Concurrent design, where communication among designers and the producers (construction foremen, site supervisors, trade contractors) can significantly improve the efficiency of production. Communication up the chain, from the people at the job site back to the designers and sales force, typically is inadequate at best.
- Time- and space-based scheduling that facilitates keeping track of who is where, doing what, and when. This type of scheduling is especially appropriate for construction activities, as crews move among sites.

The first step in this process is to collect information and form linkages. Find out what manufacturing processes are currently being used in home building—factory, modular, panelized, and stick. Determine what seems to be working well and what does not. For example, a PATH/Wood Truss Council of America sponsored effort to apply ISO 9000 type practices to framing is showing good promise. Some builders are also using JIT techniques. This strategy should include investigating the processes currently being used in the commercial and industrial construction sectors.

This also involves determining what other research is going on, what progress is being made, and what processes might apply to residential construction. For example, The Lean Construction Institute focuses on applying lean manufacturing processes to design and construction of capital facilities. Research at universities such as MIT, Stanford, Purdue, Carnegie Mellon, Virginia Tech, University of Central Florida, and others also needs to be included.

At the same time it will be necessary to identify and evaluate the effectiveness of processes currently in use in home building and publicize success stories. Some builders, especially large, national builders, are successfully using "manufacturing" processes to build homes. Also some leading-edge smaller builders can offer interesting process concepts. Denver-based Cohen Brothers, for example, has initiated a process where they build a factory at the development, then build the homes in that factory.

Next, those involved in this phase of the Roadmap should organize R&D in applying manufacturing processes to home building. The home building industry needs to find proactive ways to make this happen, such as sponsoring competitions that encourage innovation in industrialization—manufacturable house design and manufacturing process improvement. These might include design competitions for students, with emphasis on design for manufacturing. For example, the industry might sponsor a competition that encourages architecture or architectural engineering students to team up with industrial, manufacturing, or civil engineering students to conceptualize breakthrough designs and processes.

Toward the same end, competitions might also be held for companies or industry alliances. The Innovative Housing Technology Awards program is a newly-initiated competition (first awards given in February 2001), jointly sponsored by *Popular Science* magazine and the NAHB Research Center. In this competition, the reward to the winners is publicity. A PATH-sponsored competition might focus on industrialization and challenge alliances and consortia to compete. The awards could include significant funding (contract or grant) to facilitate implementation of the winning concepts.

With the organization underway, projects to demonstrate and evaluate new manufacturing processes should be identified and executed. Although volume builders, or large manufacturers of factory-built or modular homes, may have adequate capital to implement new manufacturing processes, medium and small builders or small factory-built or panel manufacturers do not. Technical assistance and perhaps funding need to be made available to companies who are willing to accept the challenge and take the risks associated with innovation.

The final step in applying manufacturing processes is to develop an ideal, integrated system that incorporates all constraints. The entire construction process becomes a single, continuous entity.

3.2 Apply Robotic Automation Technology to the Process

Information technology (IT) is the enabler for effective manufacturing processes, all of which require extensive communication, rapid and effective decision-making, and tight coordination of the many participants and tasks in the home building process. Although there are already many IT tools available for manufacturing, and some available for home construction, there are a number of important areas that require development. Another technology roadmap, *Information Technology to Accelerate and Streamline Home Building*, deals with applying IT to the regulatory process, to production management, and to making technology information accessible to the industry, as well as a common language for interoperability. However, several important areas not addressed in that Roadmap show promise for industrialization of the home building process have been identified by the *Whole House and Building Process Redesign* roadmapping team.

Robots and/or automated machines cannot only take significant labor out of the home building process, but they also have potential to significantly improve safety by replacing workers on certain jobs. For example, imagine a robot that could roof a house or dig a trench, two of the more dangerous tasks at a home building job site. Application of robots to the manufacture of factory-built homes, modular homes, and panels and trusses is not much different from their application in other industries, such as the automotive industry. Automated machines that cut framing material to size are some obvious examples that are in use currently. Although not widely used by manufacturers of homes and panels, "pick-and-place" robots have the potential of constructing major structural elements. Despite the challenges inherent in using robots in the relatively unstructured job site environment, some have been developed and are being used. A robot developed in Japan can finish concrete, and giant manipulator arms have been used to assemble modular houses. An application that seems well within the capabilities of current technology is to have excavation and grading done by robots.

The activities discussed below represent important steps in the industrialization of the home building process.

It will first be necessary to establish linkages with the Intelligent Manufacturing Systems (IMS) organization through the Innovative and Intelligent Factory Construction project. This project focuses on applying IT and robotics to construction. Also, the International Association for Automation and Robotics in Construction is doing work that may apply to residential use.

Next, a project collaboration system that provides coordination of all of the people, entities, functions, and activities involved in the construction process needs to be developed. This system would include designers, salespeople, builders, trade contractors, materials, products, and components suppliers, and perhaps even code officials and others. All parties would have instantaneous access to current design information.

At approximately the same time, a parametric planning and scheduling system that provides multi-dimensional capabilities to monitor and coordinate all of the activities in the home building process should also be developed. The system would provide real-time rescheduling in the event of inevitable construction delays such as weather.

Those involved in the process should also identify operational and developmental robots available within and outside the construction industry. They should study and document highly automated manufacturing facilities, including those outside the industry (e.g., automobile plants) and also truss building, panel building, and manufactured home building factories that currently incorporate robots. Also, this group should look at the heavy and commercial construction industries.

In order to organize the knowledge and data in such a way that facilitates the exchange of data and knowledge between design, process, and simulation tools, shared process ontologies should also be defined. This would facilitate the implementation of concurrent design, MRP/ERP, JIT, and any other processes and tools that might be used to improve production efficiency. The ontology development would be an extension of work to define a lexicon of home building terms, as described in the *Information Technology Roadmap.*

Another phase of the industrialization process would be to implement demonstration job site projects that incorporate robots and tools. The testing and demonstration of robots on job sites is challenging, but the potential payoff is high. An alliance of builders, academicians, manufacturers, and government could implement trials in housing developments.

Further down the road it would be useful to develop a three-dimensional computer aided design/computer aided manufacturing (3-D CAD/CAM) system that facilitates design of houses that meet performance goals (e.g., PATH goals for affordability and energy efficiency), aesthetic and lifestyle requirements for the consumer, and code requirements for the area in which it will be built. At the same time, the system would assure that houses were designed for manufacturing.

Developing an open system architecture for manufacturing systems that will allow for effective, efficient integration of people and tools to accomplish the construction of homes would be the next progression of this work. This would be a sort of "plug and play" environment in which software or subsystems from different vendors could not only exchange information, but would also be functionally integrated to achieve true interoperability. There are already such efforts underway. For example, the Computer Integrated Manufacturing Open System Architecture (CIMOSA) Association is involved in the definition and promotion of an open architecture for enterprise integration. Members of the CIMOSA Association are industrial and research organizations involved in exploitation of CIMOSA or interested in the subject of enterprise integration. Also, the National Institute of Standards and Technology (NIST) is working on an Intelligent Open Architecture for Control of Manufacturing Systems.

The final initiative in the application of robotics and automation in home building would be to develop an automated factory of the future for testing, demonstration, and evaluation of automation. This might be established as a center of excellence at a university. For example, during the 1980s and 1990s, Purdue University had a shop-floor automation facility that had similar goals but was not oriented to house construction.

4 IMPROVE THE CONSTRUCTABILITY OF HOUSES

Houses today are designed pretty much the way they were in the 19th century when balloon construction was introduced. As new subsystems came along—indoor plumbing, electric wiring, central HVAC—they were simply "added to" the home, not "integrated into" the home.

We have settled on standards (e.g., 16-inch centers for studs), which have certainly helped the industry to make progress, but at this juncture need to be reexamined. For example, studs on 24-inch centers have been shown to provide adequate structural strength, yet require less material and labor to assemble the walls, and 24-inch centers provide superior insulation. (It should be noted, however, that increased spacing of 2x4s may require stronger sheathing, is limited to single-story houses, and may require special design details such as "in-line framing" or "point loading" where joists, studs, and trusses are all aligned.)

Houses need to be designed so that they are constructable or manufacturable. The variety of different parts, the total number of parts, and their ease of assembly must be addressed comprehensively and systematically. Although builders, site foremen, and tradespeople often make ad hoc changes or improvements to designs that will improve constructability, there needs to be a mechanism for collaboration of designers, builders, trade contractors, and regulators and a way to get information to other colleagues who might benefit from it.

In addition to making incremental improvements in relatively conventional stick-built or panelized construction, the industry needs to think outside the box. Materials and structural ideas from other industries need to be examined and applied to home building as appropriate. For example, use of composite materials along with advanced insulation material technology (possibly from the apparel industry) could result in lightweight, high-performance panels. Research and development is needed in those areas that can make the house easier to construct, reduce labor costs, reduce the number of components and/or the number of different components, reduce materials needed, and make interfaces more failsafe.

The strategies for implementing this part of the Roadmap are shown in Figure 4 and summarized in the following paragraphs.

4.1 Disentangle Mechanical Systems

Disentangling of mechanical systems is an evolutionary, incremental step in reducing the cost and improving the performance of mechanical systems. Disentangling assumes that the systems—plumbing, HVAC, electrical, and communications—remain separate entities but are designed and installed in a non-interfering fashion. It would assure that systems are correctly sized, that they are designed to fit, that the installers install them where they were intended to be installed, and that they are installed in the most efficient sequence.

The first step in disentangling is to develop or identify products or systems that will reduce interference and competition for space, e.g. mini-duct, high velocity

HVAC distribution, surface wiring, or surface raceways for wiring. Another possibility is to use utility chases that might include electrical and communication wiring and even plumbing. Mini-split heat pumps that do not require ductwork are an example of a technology that is available currently, but has some cost issues.

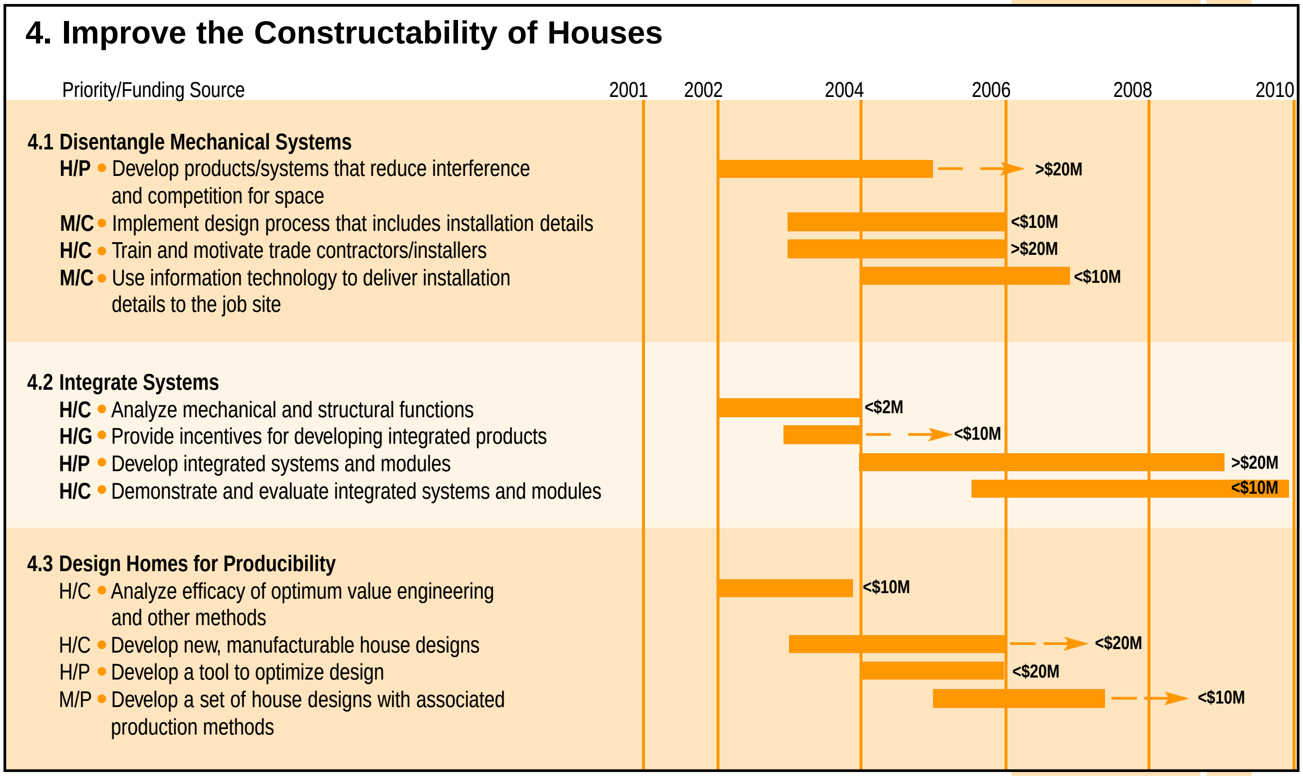

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Figure 5

Next it would be necessary to implement a design process that includes installation (routing and assembly) details and a required sequence of installation. Perhaps standard protocols could be defined for routing the utilities in a house.

Training and motivating trade contractors and installers to understand and use installation details is the next challenge in the disentangling process. The challenge is that tradespeople often do not follow installation diagrams, even if they are available.

Finally, as a longer-range activity, it would be necessary to apply IT solutions to deliver installation details to installers at the job site. For example, details might be available on a "heads-up" display showing the installer where to run ductwork or plumbing.

4.2 Integrate Mechanical and Structural Systems

The thrust of integration is to combine functions to reduce the total cost of the systems, to reduce the labor required for installation, and/or to improve the energy efficiency of the final product. A current example of this idea (and a PATH Technology Inventory item) is a water heater that also has space heating capability—the hot water heater also heats a coil in the air handler. A future integrated system might include house designs that eliminate the need for ductwork and circulating fans by using natural circulation and ceiling fans.

A good starting place for systems integration is an analysis of the mechanical and structural systems functions in the house and details of their requirements. In addition to the requirements of the "systems," the needs of the residents should be considered. Considerations should include both customer perception and human factors engineering.

Following that analysis, it would be necessary to create and provide incentives to the industry for developing integrated products. One of the difficulties of combining mechanical system functions is the manner in which the industry is segmented. Appliances, HVAC (furnaces/air conditioners/heat pumps), plumbing products, and electrical products typically are all produced by different companies. Also, they usually are installed by different trade contractors. Therefore, there needs to be more encouragement for integration in the industry. The industry and the government need to provide incentives for developing integrated products and provide the environment conducive to new technology insertion.

The next task is to develop the actual integrated systems and modules. Individual manufacturers as well as consortia, alliances, and centers of excellence need to undertake R&D to develop integrated products or systems, such as:

- Flooring modules incorporating HVAC ducting or radiant heat;
- Utility system modules that incorporate furnace, hot water, electrical, and communications; and
- Combination ground loop heat pump/refrigerator.

The final step in achieving integrated mechanical and structural systems is to demonstrate and evaluate the integrated systems and modules in the field. The existing PATH mission and structure provide for such demonstrations and evaluations to help early adopter builders learn how to use the product, to evaluate the viability of the product, and to make other builders aware of the product.

4.3 Design Homes for Producibility

The concept of designing for manufacturing efficiency has been applied successfully in many industries for decades. The idea is to reduce the overall number of parts and the number of different kinds of parts, and to use parts that are easy to assemble and install—resulting in lower costs for materials and labor. Design for manufacturability can include incremental improvements, such as making stick-built or site-built houses less costly to build, but can also include more revolutionary improvements, such as using panelized or modularized new materials. For example, an extremely lightweight, extruded composite wall panel might dramatically reduce the parts count and labor costs.

Designing for construction might also include ideas for meeting residents' needs by using advanced architectural design concepts. For example, can a smaller room be made to "live bigger?" Can flexible, adaptable space be incorporated?

In order to design homes with an eye toward producibility, the first step is to analyze the efficacy of optimum value engineering (OVE) and other methods for reducing material and labor content in houses. OVE and structural integration would "redesign" conventional, stick-built houses with fewer parts and less material to make them easier to build. Even without significant technology developments, many easily implemented design changes are available already that can significantly decrease the cost of houses whether the house is built onsite or in a factory. OVE looks at the framing process as a whole, and optimizes the use of materials, labor, and cost, while offering higher quality and improved energy efficiency. Structural integration, or exploiting the structural properties of all the materials comprising a building, also offers potential savings. For example, the overall static load capability of a wall—including sheathing, studs, and perhaps even gypsum board—need to be considered when designing a wall. The work that already has been done needs to be collected and the reasons for lack of success need to be identified. For example, were the techniques not adequately exposed to designers? Was it too difficult to educate local code bodies?

After the analysis it would be beneficial to develop new, manufacturable housing designs that use concepts and methods discussed above and new concepts that the industry has not addressed yet.

Developing a tool to optimize the design of the house would follow. Although there are many CAD packages available to the home building industry that assist designers in designing aesthetically pleasing and structurally sound homes, there are none available that address the entire set of parameters that are critical when building a house. These parameters include manufacturability (labor content, material efficiency, parts count, cycle time), cost, energy efficiency, durability, and code constraints. A tool needs to be developed that will address all of these factors during the design phase, and which allows the designer to perform tradeoffs and analysis that result in a design optimized for the constraints. Stand-alone tools already exist for the design of the house and materials take-off and for energy efficiency analysis. A tool for durability analysis is being developed by NIST. These tools need to be integrated and a manufacturability tool needs to be developed and integrated as well.

The roadmapping group felt that the last critical step in designing for producibility was to develop a set of house designs and corresponding production methods or processes suitable for use by small builders who want higher production efficiency. The houses would be designed for manufacturability, although they might be stick-built, onsite, or panelized. The designs would include variations to allow some degree of "customization."

Production methods or processes would be specific to a particular house design, with drawings provided for all subsystems, including assembly details. The designs would include lists of materials and alternative materials. The specification of production methods that would accompany each design would indicate how the home should be constructed, including the construction sequence, assembly instructions (via laptops or video tapes), required equipment, etc. It may be desirable to provide all of this as a coordinated software package.

5 MOVE MORE OF THE HOME BUILDING PROCESS INTO THE FACTORY

The processes and tools that can be used in a factory may be difficult or impossible to use on a job site. Building in a factory offers control—of the processes, of the people, of the environment. This is not a new strategy. It has been used for decades for “manufactured homes” or HUD-code homes. In 1997, approximately 350,000 of these homes—single- and double-wide—were shipped, compared to about 1.15 million “conventional” (includes panelized) home starts. In 1997, less than 50,000 modular homes were shipped. (These numbers are from “Factory and Site-Built Housing, A Comparative Analysis,” U.S. HUD PD&R, October 1998.)

As the above-quoted report indicates, manufactured homes are doing well in the marketplace for a variety of reasons, the most important of which is a significantly lower price than site-built homes. The fact that their appearance (especially multi-section) increasingly resembles site-built housing is another important factor. Two-story manufactured houses are now available.

However, factory-built homes, including modular, are subject to a number of transportation constraints, including:

- Large modules or whole houses need to be transported over highways.
- Distance from the factory to the building site is also an issue, as transportation of these large modules is costly.
- Tools for putting modules or factory-built houses in place are also an issue. A relatively large and costly crane or cherry picker is typically required.

A process that reduces or eliminates the transportation constraints, devised by Cohen Brothers Builders, is to erect a factory in the housing development (at least 200 homes to be economically feasible). Complete houses are constructed in the factory, then transported the short distance to their foundations on a special dolly.

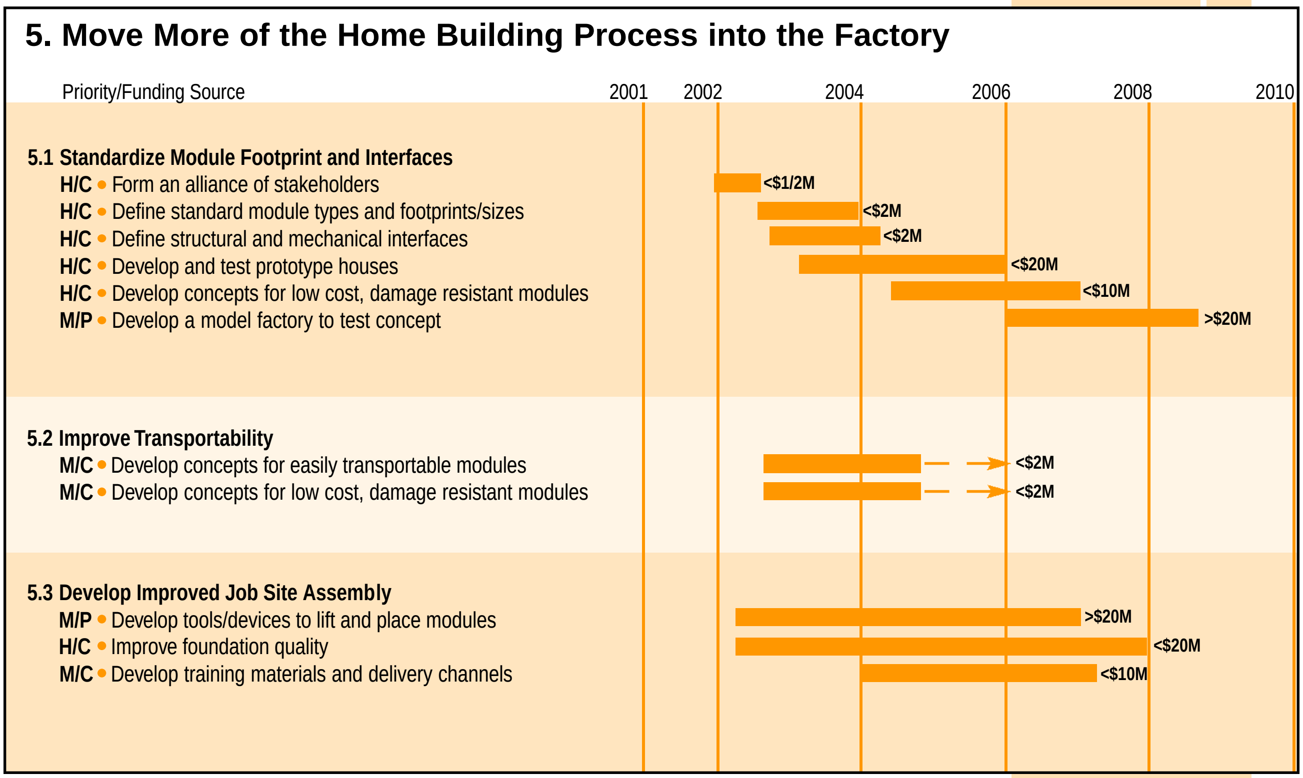
Consumer acceptance is another important issue for factory-built homes. Consumers often view these homes as inferior in design and quality to site-built homes. Also, manufactured homes, and to a lesser extent modular homes, have limited capability to allow personalization or customization.

The strategy outlined below, if successfully implemented, will provide more flexibility and increased production efficiency in factories (as well as on the job site). This section describes the three areas that require research and development to significantly improve the success of factory-built homes in the industry. This part of the *Whole House Roadmap* is illustrated in Figure 6.

5.1 Standardize the Module Footprint and Interfaces

The premise is to have only a few basic module sizes, yet allow significant variation in appearance and in the way they are configured to provide the customization consumers want. Potential benefits of standardizing are:

- Reduces the number of components;
- Allows for interchangeability of parts or components from a variety of manufacturers;
- Reduces the onsite tasks to a rather simple and standardized assembly;
- Provides options, variety, and personalization in the areas important to consumers by allowing variations in shapes, exterior styles, interiors, and trim levels; and
- Simplifies the inspection and approval process as most of this is can be moved to factories.



Key: Priority: L, M, H = Low, Medium, High
Funding Sources: G, P, C = Government (public), Private Industry, Combination
Funding amounts are approximations.

Figure 6

The fundamental idea is to establish an open set of standards that allows modules built by one or a variety of manufacturers to be assembled as "building blocks" on the job site. The interfaces between these modules would provide sound and secure connections for both the structures and the utilities. The sizes would be standardized to join together (ideally snap together) so as to minimize any onsite connection construction. The modules would have a high degree of interior and exterior finish installed.

The first step in this process, as with other roadmap strategies, is to form an alliance of stakeholders to define and agree to the standards necessary. The alliance should include manufacturers of modular and manufactured homes, suppliers, builders, trade contractors, regulatory officials, and designers.

Once established, this alliance should define standard module types and footprints or sizes. A relatively small number of footprints will need to be defined in order to maintain the economies of scale. Possible module types are: bathroom, kitchen, utility, bedroom, and living/dining/family room. Examples of the types of modules that should be considered with several variants of sizes and features for each include:

- Complete kitchen with appliances, cabinets, and flooring installed;
- Complete bathroom with plumbing fixtures installed;
- Decorative features for personalization (e.g., dormers, porches, etc.);
- Garages;
- Roofs complete with shingles; and
- Floor modules, including mechanicals.

Once the standard development is underway, structural and mechanical interfaces need to be designed to provide structural integrity and allow for quick assembly but resist incorrect assembly. Easy-to-connect, reliable interfaces for HVAC, electrical, plumbing, and communications need to be defined and designed. This area will require significant research and development. Also, reliable, foolproof structural connections are needed. Ideally, the modules would simply snap together. Initial evaluation of the interfaces and connections should be accomplished via computer modeling, if possible.

The next step is to to have the stakeholders work with the national code bodies and selected state and local code offices to develop a streamlined approach to approvals and inspections. The goal is to move as much of the inspection process as possible into the factory. For example, modules manufactured under ISO 9002 (or similar) quality systems could be pre-approved or certified so that building inspection of each individual trade is not required. One inspector could handle sign-off on all systems assuming the certified modules were properly interfaced.

Designing, developing, and testing prototype houses using the standard structural and mechanical interfaces described previously would be the next phase of work. This would include testing in the field and evaluation of the factory manufacturing, field assembly, durability, and quality of the homes.

The final initiative is to develop a model factory using processes and tools developed under the strategies in this Roadmap to test the concept. The factory could be located in a center of excellence, but likely would be more effective if it were developed by a manufacturer or alliance.

5.2 Improve Transportability

The fundamental issues with transportability that require research and development are the size constraints imposed by highways and the challenge of transporting large modules or whole houses without damaging the units.

To make these improvements, concepts for easily transportable modules must first be developed. As a general rule, it makes sense to design a house with fewer, larger modules instead of many, smaller modules because the bigger the modules, the more construction takes place in the controlled environment of the factory. Making bigger modules offers potentially greater savings of time and money. However, some hoped-for cost savings are offset by higher transportation costs for oversize loads and the need for a crane to unload and position the modules. Ideally, modules are small during transport and are easily "expanded" at the job site.

Damage to modules during transport or off-loading is a real and persistent problem in factory-built homes. Systems, designs, and procedures need to be established to prevent damage to the modules during transportation and installation. For this reason, it is necessary to develop concepts for low-cost, damage-resistant modules that will be sufficiently rigid to withstand transportation, but with little or no added cost and weight. Despite the potential savings of using a prefabricated module, the builder cannot afford to repair modules that arrive damaged. The use of complete box modules would result in doubling of some wall and floor panels. The extra use of materials would increase cost. Techniques and systems need to be developed to eliminate this redundancy.

5.3 Develop Improved Job Site Assembly Techniques, Tools, and Training

Assembling modules and completing the house rapidly, cost-effectively, and correctly at the job site is a critical phase of the construction process. Although constructing modules in the factory eliminates most of the skilled labor required at the job site, it is important to look for better ways to put the modules together at the site.

One way to improve the site assembly process is to develop tools and devices to lift the modules and to put them in place quickly and accurately. These devices would be smaller, less expensive, safer, and easier to operate than currently available cranes or cherry pickers. Also, it would be useful to look at techniques and devices in the United States and around the world for positioning or locating the modules on the foundations.

It is not only important to improve the assembly and installation, but also the quality of the foundation on which the home is placed. The manufactured, modular, and panelized home industries overwhelmingly agree that the dimensions and levelness of foundations are amoung the most critical factors affecting the speed and quality of installation. In site-built homes, the framing carpenters typically try to compensate for foundation imperfections (although there is a large penalty in labor, not only for the framers, but also for other trades who must compensate for non-squared or non-leveled rooms). Areas that need to be considered for improved foundation quality include:

- Training the cement workers;
- Providing improved tools to control size and level; and
- Implementing a quality program for the concrete and masonry contractors.

The cement and masonry sector of the home building industry needs to be brought into the alliances mentioned earlier in order to facilitate these solutions.

Finally, it is critical to remember that the erection or assembly of a factory-built home on the job site requires significantly different skills than any required for stick-built homes. The truss industry has already experienced the kind of safety and quality problems that can arise when framers who lack experience with trusses are expected to install them. That is why training materials specifically geared toward these processes and these installers must be developed, as well as the necessary channels for delivering training. The training of assemblers might occur in junior colleges and vocational schools, but training of people currently in the workforce might be better accomplished by other means, for example, on the job site.

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